SOUND, LIGHT

AND

HEAT

BY

obinson
MARK R. WRIGHT

HEAD MASTER OF THE HIGHER GRADE SCHOOL, GATESHEAD

LONDON
LONGMANS, GREEN, AND CO.
AND NEW YORK : 15 EAST 16th STREET
1887

PREFACE.

THIS volume is an elementary text-book on Sound, Light, and Heat treated experimentally. It is essential that the experiments should be performed. The numerical results which illustrate the text, should not take the place of measurements, made by the student.

The experiments demand no expensive apparatus ; the aim has been to avoid elaborate instruments; descriptions of the apparatus used, appear in the book or in the Appendix. Many of the engravings are copied from pieces of apparatus in use. The experiment on p. 3 was introduced to English readers by Mr. H. G. Madan.

The results obtained from the experiments make no claim to great accuracy. The student should avoid attaching to his calculations greater value than they deserve; he should consider the apparatus with which he works ; it is a strong temptation to calculate to five or six places of decimals when probably not more than the first place can be relied upon. The portions of the text, between thick brackets, may be omitted on the first reading.

While attempts have been made to prevent the student forming notions at variance with modern theories, little space has been given to such theories. A beginner's time is best spent in examining the facts of science.

The volume embraces the work usually taken in elementary examinations, such as the elementary stage of the Science and

Art Department, the papers on Light and Heat of the London University Matriculation Examination, and the papers on Heat of the Oxford and Cambridge local examinations.

Numerous examples are given frequently throughout the work; Science has been slow in copying from Arithmetic in this matter. A large number of the examples are selected from Examination papers; they include the whole of the questions in the elementary papers of the Science and Art Department, during the last nine years, and the greater proportion of those in the advanced papers.

The usual title, 'Sound, Light, and Heat,' is retained, but 'Heat' being considered the most suitable as an introductory subject, is placed first in the volume.

M. R. W.

GATESHEAD: *October* 1887.

CONTENTS.

HEAT.

SOUND.

HEAT.

CHAPTER I.

HEAT AND TEMPERATURE—THERMOMETERS.

1. HEAT AND TEMPERATURE.

TOUCH the part of the fender in front of the fire. It feels warm. The fire-bars feel hot. A piece of iron on the table feels cold. *The agent which produces the sensations of hotness, warmth, coldness, and similar sensations is called Heat.*

Plunge the hand into vessels containing water. The terms hot, very hot, warm, lukewarm, cold, are used to express the state or condition the water is in with respect to the heat that affects the hand.

The names used are names of temperatures.

The Temperature of a body is its condition with respect to its heat that affects the senses.

The hand in the last experiment was used to measure roughly the temperature.

A body that measures temperature is called a Thermometer.

By using the hand, a table like the following could be constructed :—

Temperatures.

—	Very hot	Hot	Warm	Cold	Very cold
Iron	in the fire	near the fire	at the end of the fender	on the table	—
Water	—	boiling	—	spring	in winter

It is not asserted that 'hot temperature' means the same in the case of the iron and the water; compare the expressions a high house, a high mountain.

Place a piece of hot iron upon a piece of cold iron. After a while the hot iron loses heat and its condition with respect to its sensible heat (its temperature) falls. The cold piece gains heat and its temperature rises.

Temperature is a state or condition; it is no more *heat* than the *level* of the water in a pond is the *water* itself. *Heat* and *temperature* are analogous to *water* and *level.* Water flows from a *high level* to a *lower level,* just as heat flows from bodies at a given temperature to bodies at a lower temperature.

The level of water is generally measured from the bottom of the containing vessel; in a dock the positions of the level at the highest and the lowest tides might be the most important positions, and there would be no difficulty in dividing the distance between these levels. The level at any number on such a scale would give much useful information. We shall see how similar 'fixed points' may be used in scales of temperature.

2

The hand was used as a thermometer and temperatures were compared when its use was restricted to bodies composed of the same kind of matter.

Touch pieces of wood, iron, and flannel that have been some time in the room, with the hand. The flannel is warm, wood is fairly warm, iron is cold.

Place the three substances in a warm oven, or place them in an empty beaker floating in a larger beaker of boiling water. In five minutes test their temperature again with the hand.

The iron is hot, the wood is very warm, the flannel is warm.

In each case, as will be shown later, the bodies are at the same temperature. If in either case any two were placed in contact there would be no flow of heat.

While the hand may still be used to compare the temperatures of bodies composed of the same substance, its use as a general thermometer must be rejected.

Take three vessels ; into the first pour water as hot as the hand can bear, into the second lukewarm water, and into the third cold spring water. Plunge the right hand into No. 1, the left hand into No. 3 ; after a few minutes place both hands into No. 2. No. 2 feels cold to the right hand and warm to the left hand.

Both hands cannot be depended upon to indicate the same temperature.

The hand may be a good thermometer as long as its use is confined to water. Bath attendants are very expert in determining within a few degrees the temperature of the bath.

3. The General Effect of Heat on Solids.

General Experience.—Iron bridges are never fixed at both ends; one end at least rests upon rollers to allow for the lengthening of the bridge on hot days. For the same reason a space is left between the ends of the rails on a railway.

Take a rod of iron 18″ long. Place it as in the sketch (fig. 1), resting upon two hard wood blocks. Make one end firm by placing a heavy weight upon it. Rest the other end upon a fine sewing needle. (The needle should, if possible, rest upon a smooth piece of metal placed upon the block.) Fasten a straw 6″ long to the eye of the needle with sealing-wax. Fix a divided semicircle of cardboard behind the block. Place the needle so that the straw is vertical. With a spirit lamp heat the bar, moving

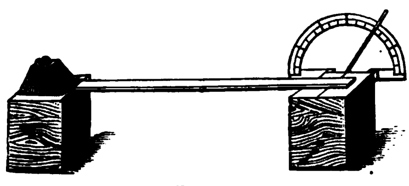


Fig. 1.

the lamp from end to end. The index moves to the right. This is due to the expansion of the bar and the consequent rolling of the needle. As the metal cools, the index moves to the left. Repeat the experiment, using a brass rod, a glass rod, etc.

Solids, as a rule, expand on the application of heat. The expansion in length is called the linear expansion of solids. As a solid can expand in three directions, its volume will increase on heating. Fig. 2 illustrates the cubical expansion of solids. A brass or copper ball when cold is just able, in any position, to pass through the ring *m*; after being heated it is unable, in any position, to pass through, on account of the expansion of the ball. This apparatus is called *Gravesande's ring*.

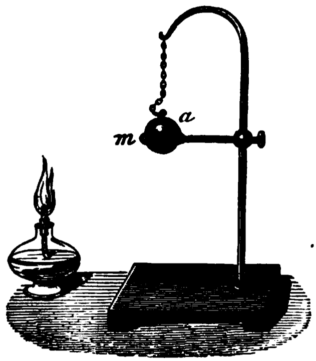


FIG. 2.

Use the copper ball. Cut a hole in thin sheet iron that just allows the ball to pass when cold. Place the plate on the tripod stand, and perform the experiment.

4. THE GENERAL EFFECT OF HEAT ON LIQUIDS.

Take a 2-oz. flask, fill it with clean water that has been boiled and allowed to cool. Colour the water with red ink. Fit the flask with a cork, and pass a tube 12″ long through the cork. Insert the tube and cork in the flask (fig. 3). The water rises in the tube. See that there is no air beneath the cork. Rule lines on a strip of drawing paper at equal distances apart; fasten this scale behind the tube.

Place the flask in a beaker of warm water, and notice (*a*) a slight descent of the liquid, followed by (*b*) a gradual ascent.

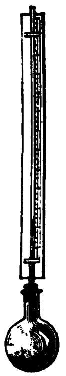


FIG. 3.

Remember that solids expand on being heated. The heat affects the glass first; it expands, its volume is increased; therefore a slight descent of the liquid takes place. As soon as the heat reaches the water in the flask it expands more than the glass has expanded, and therefore the liquid is forced up the tube.

Fit up two similar pieces of apparatus, using methylated spirits (impure alcohol) and mercury instead of water. Do

not colour the spirit, and remove all flames. By a few trials, it can be arranged so that the water, the spirit, and the mercury stand at the same height in the tubes when all are at the temperature of the room. Place all three in a basin of warm water. The alcohol rises higher than the water or mercury, and the water higher than the mercury.

Liquids expand on being heated.

EXAMPLES. I.

1. How would it affect the rise of the liquids if a tube be used (*a*) with a narrower bore, (*b*) with a wider bore?

2. What would be the effect of using a larger flask?

3. Suppose the glass did not expand, how would this affect the rise of the liquid?

4. Define Heat and Temperature. Is temperature heat?

5. PRINCIPLE OF THE THERMOMETER.

The expansion of solids and liquids suggests a method of making a thermometer. Might not the lengthening of a bar of iron indicate a change of temperature? The difficulty is the small elongation. The expansion was only demonstrated by using a flame to the bar. With liquids the expansion is evident. The experiments show that alcohol will be more suitable than water or mercury, but alcohol and water boil and pass into vapour before mercury; mercury is therefore used. It will be advisable to use a tube with a fine bore (Examples I.), and also a large flask, if a small increase of temperature is to be made apparent by the rise in the tube. A large flask is objectionable, inasmuch as it takes a long time to heat the contained liquid. By using a small vessel and a tube with a very fine bore the best results will be obtained.

If the top of the tube be open, impurities get into the liquid, the liquid evaporates, and its position is also affected, as will be seen later, by the pressure of the atmosphere; it would be useless merely closing the end of the tube, as the imprisoned air would resist the rise of the liquid.

Conclusion.—Mercury is a suitable liquid to use in a thermometer. The tube should have a small bulb and a very

fine bore; air should be removed from the tube and the tube should be closed.

6. To Make a Mercurial Thermometer.

There is a fair amount of difficulty in this, and the fumes of boiling mercury are dangerous. The student should be content with reading the description. The construction of the alcohol and water thermometers may be safely attempted.

The Tube.—Select a tube with a uniform bore, close one end, and blow a small bulb, D; blow a bulb, C, higher up the tube, and cut off the tube just above C. Pour a little pure mercury into C, warm D gently; air is forced out; remove the flame, on cooling part of the mercury is forced into D; repeat this until D is half-full. Fill C and boil the mercury in D; all the air is forced out along with the mercury fumes; on cooling, D and the tube will be quite full. Place the tube horizontally; the mercury will leave the bore below C, falling into C. With a very small blowpipe flame soften the tube at that point and draw it out, leaving it as at E. With a file cut off at E. Place the tube in a bath of boiling oil; the mercury expands and oozes out at the point; when it has ceased running out, close the point with a very small flame, increase the strength of the point by heating the glass. Let the bath cool down. The thermometer will now appear as F, and temperatures can be indicated up to the boiling-point of oil. If higher temperatures are needed, boiling sulphur could be used; if lower temperatures, boiling water.

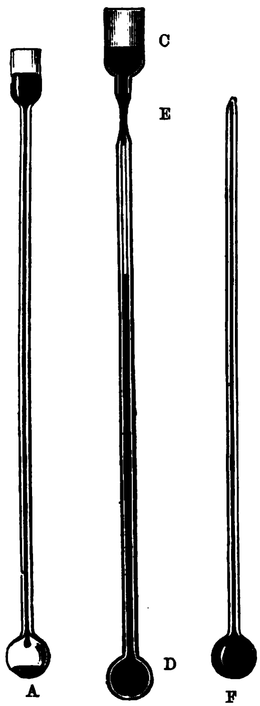


Fig. 4.

A scale behind the tube might answer the purpose of one ex-

perimenter, but as different persons wish to compare temperatures, two fixed points have been agreed upon (see § 1).

7. THE FIXED POINTS.

It is found that (1) the temperature of melting ice is always the same wherever or whenever the experiment is tried ; (2) that the steam of boiling water is always at the same temperature if the pressure be the same. The standard pressure in England is taken as a pressure of 30 inches of mercury on the square inch, on the Continent as 760 millimetres of mercury ; that is, the barometer must either be standing at 30 inches, or allowance must be made for any variation.

I. THE FREEZING-POINT.—Clean snow or well-pounded ice is placed in a vessel (fig. 5). The bulb is inserted, so that it is surrounded. It is left for a quarter of an hour and moved, so that the thread of mercury is seen just above the ice. A scratch is made with a file ; this is the freezing-point. The water from the melted ice escapes at the bottom.

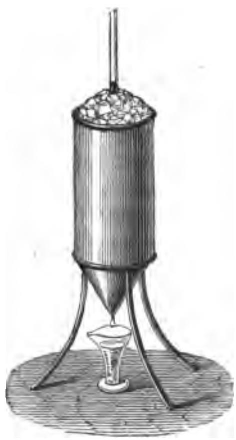


FIG. 5.

II. THE BOILING-POINT.—The bulb is placed in a metallic vessel (fig. 6), so arranged that the tube is heated by steam. By following the direction of the arrows it will be seen that the inner tube A is prevented from cooling by the steam surrounding the outside of A. The thermometer is moved until the mercury is just seen above the cork (*a*) ; when it is stationary a mark is made ; this is called the boiling-point.

If the barometer be not at 30 inches a correction is made from tables.

8. THE SCALE.

The distance between the fixed points is divided into equal parts called degrees. Three methods are followed :—

1. *Fahrenheit Scale.*—The freezing-point is called 32°, the

boiling-point 212°. Therefore the distance is divided into 180 parts. This scale is in common use in England.

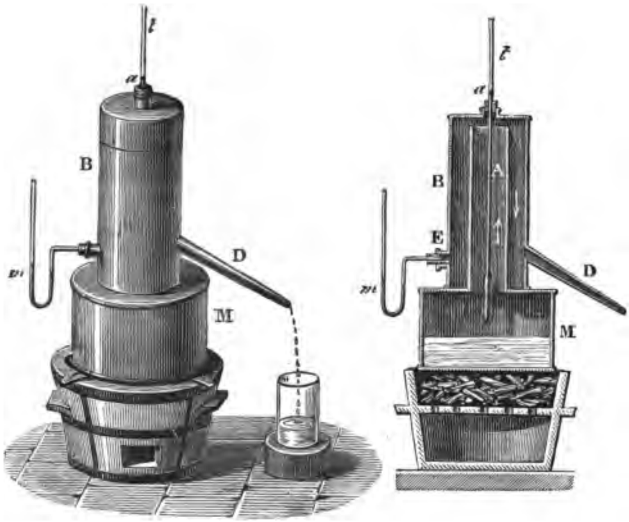


FIG. 6.

2. *Centigrade Scale.*—Freezing-point is 0°, boiling-point 100°. This is in common use on the Continent and among scientific men in England.

3. *Réaumur's Scale.*—Freezing-point is 0°, boiling-point 80°. This scale is in common use in Germany.

The divisions are continued above and below the fixed points, the divisions below 0° being indicated as −1°, −10°, −15°, etc.

180° Fahrenheit = 100° Centigrade = 80° Réaumur ∴ 18° F. = 10° C. = 8° R.

EXAMPLES. II.

1. How many divisions of the Centigrade scale are equal to 54 divisions of the Fahrenheit scale on the same thermometer?

2. On a certain Centigrade thermometer 12° measure an inch; what would 12° Fahrenheit measure on the same thermometer?

9. Relation of the Scales.

Suppose a thermometer graduated according to each scale. To compare the readings when the mercury is at a certain height xy :—

Let f, c, r be the number of degrees according to each scale (fig. 7).

Then $\dfrac{f-32}{180}=\dfrac{c}{100}=\dfrac{r}{80}$,

because the numerator and denominator of each fraction represent the same distance;

$$\frac{f-32}{18}=\frac{c}{10}.$$

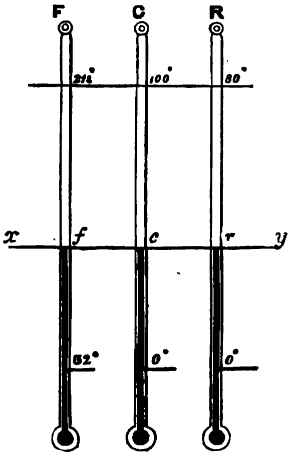


Fig. 7.

1. A thermometer reads 60° F.; what would its reading be in degrees Centigrade?

$$\frac{f-32}{18}=\frac{c}{10} \qquad \therefore \frac{60-32}{18}=\frac{c}{10}$$

$$\therefore c=\frac{10\times 28}{18}=15{\cdot}5° \text{ C.}$$

2. Change 15° C. into the Fahrenheit scale.

$$\frac{f-32}{18}=\frac{15}{10} \qquad \therefore f-32=27$$

$$\therefore f=59°.$$

3. What is -18 F. on the Centigrade scale?

$$\frac{f-32}{18}=\frac{c}{10} \qquad \therefore \frac{-18-32}{18}=\frac{c}{10}$$

$$\therefore c=\frac{10}{18}\times(-50)=-27{\cdot}8°.$$

The student can, as an exercise, write down the relation between degrees Centigrade and Réaumur. The latter scale is of slight importance in England.

EXAMPLES. III.

1. Define Heat and Temperature. What is meant by sensible heat?

2. What is a Thermometer? what are the advantages and disadvantages of alcohol compared with mercury?

3. Describe the construction of a mercurial thermometer.

4. How are the fixed points on the stem of a mercurial thermometer determined? Into how many parts is the distance between them divided on the Fahrenheit scale? To what temperature on the Centigrade scale does 179° F. correspond?

5. Change the following degrees Centigrade into degrees Fahrenheit: 50, 10, −7, 180, 32·5.

6. Express 90°, 30°, 15°, 32°, 180° Fahrenheit in the Centigrade scale.

10. ALCOHOL THERMOMETER.

A bulb is filled with coloured alcohol as with mercury. It is graduated by placing it in baths at different temperatures with a good mercury thermometer, and the same readings are marked on the alcohol thermometer as are indicated by the mercury thermometer. It can be used for lower temperatures than mercury. Mercury freezes 39° below zero on the Centigrade scale (−39° C.), and is then useless. Alcohol only freezes at −150° C.

EXAMPLES. IV.

Construction of thermometer.

1. Why should care be exercised in securing a tube of uniform bore?

2. What are the objections to constructing a mercury thermometer and leaving the top of the tube open?

3. How is a thermometer filled?

4. Why is it necessary to boil the mercury?

5. What are meant by 'the fixed points'? what precautions must be taken in obtaining the boiling-point?

6. Change the following degrees C. into F. and R.: 15°, 30°, 17·5°, 0°, 100°, −30°, −10°. F. into C. and R.: 180°, 212°, 70°, 60°, −12°.

7. How would you construct a water thermometer? how would you graduate it?

8. Under what circumstances is an alcohol thermometer used instead of a mercurial thermometer? How is an alcohol thermometer graduated?

9. What is meant by a 'degree' of heat, say 14 degrees Centigrade? What is meant by a change of temperature?

11. To Test the Position of the Fixed Points on a Thermometer.

I. Freezing-Point.—Use a common tin instead of the apparatus in fig. 5. Punch several holes in the bottom, fill it with clean well pounded ice. Insert the thermometer, resting the tin on a tripod stand. Observe the temperature.

Add a little salt and note the temperature.

II. Boiling-Point.—Insert a cork through which passes a glass tube into a long test-tube. With a small blowpipe flame soften the glass at *a* (fig. 8.); when it is red blow through the tube; a small hillock is formed: reheat and blow; the hillock breaks and a hole is formed. Remove the cork and insert a cork with two holes; through one pass a thermometer, through the other a tube passing nearly to the bottom of the test-tube. Surround the neck of the tube with a piece of india-rubber tubing, so that it fits tightly into a flask. Boil water in the flask; the thermometer is surrounded by steam. Note the position of the boiling-point. Add a little salt to the water and boil again. Place the thermometer *in* the salt and water and observe the temperature, also in water containing calcium chloride.

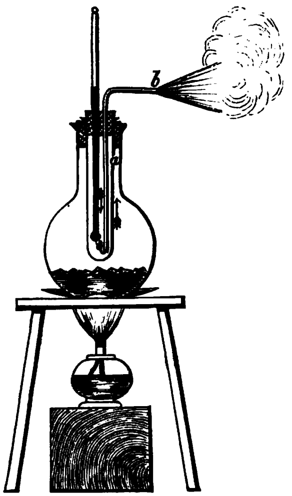


Fig. 8.

Example.

1. Freezing-point with clean ice = 0° C.
2. ,, ,, ,, ice and salt = – 10° C.
3. Boiling-point with steam from water = 100·5° C. Error ·5°.
4. ,, ,, ,, salt and water = 100·5° C.
5. ,, ,, ,, calcium chloride and water, the thermometer dipping into the water = 107° C.

Conclusion.—For freezing-point use *clean* ice. Always re-test thermometers with steam from water; on the above

thermometer the boiling-point has been marked ·5° too low. Impurities in water affect the boiling-point of water, but do not affect the temperature of the steam from such water.

12.

The mercurial thermometer can now be used to test the temperature of a body. Suppose it touches a piece of warm iron, heat flows from the iron to the mercury; the bulb being small the heat lost by the iron is inappreciable; soon the iron and the thermometer are at the same temperature, which is practically that of the piece of iron.

With the thermometer test the temperature of various bodies in the room. Show that all are at the same temperature. Test the temperature of bodies placed in an oven. Re-read §§ 1 and 2.

Attach a tube bent at right angles to the apparatus (fig. 8) where the steam issues; let the bent part dip into water so that the steam issues, say, 9 inches below the surface; boil and notice that the temperature rises. The steam is under increased pressure; this causes a rise of temperature. A change in the pressure of the atmosphere similarly affects the boiling-point, hence the reason for noting the height of the barometer when the boiling-point is taken.

EXAMPLES. V.

1. Explain how the fixed points on the stem of a mercurial thermometer are obtained. Why is it necessary, in marking the 'upper fixed point,' to take note of the height of the barometer?

2. Does a thermometer measure heat?

3. Give the reason for determining the upper fixed point by means of steam rather than by boiling water.

CHAPTER II.

EXPANSION OF SOLIDS AND LIQUIDS.

13. Coefficient of Linear Expansion.

Refer again to the experiment in § 3. Let the sketch represent a section of the rod and needle very much enlarged. The pointer has moved 30°.

Suppose that the needle, instead of rolling, turns upon an axle. Before turning, the points b and b' would be in the position a. The arc ab = the distance ab'. If the diameter of the needle be known and the angle be measured, evidently the distance ab' can be calculated.

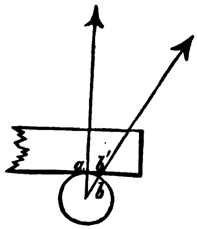


Fig. 9.

Suppose diameter $= 1''$; the circumference $= 2 \times \pi \times \frac{1}{2}$, $ab' =$ arc ab.

$$\text{arc } a\,b = \frac{\pi}{360} \times 30 = \frac{\pi}{12} = \frac{3{\cdot}1416}{12} = {\cdot}262 \text{ inch.}$$

Thus the elongation could be measured. The elongation of a bar is not measured in this way; the example is given to show that the numbers to be afterwards given are the result of actual measurements carefully made.

A bar of iron measuring 1 foot 6 inches at the temperature of melting ice measures 1 foot 6·036 inches at 100°.

A number of results such as this would be difficult to remember, and would be of little use for purposes of comparison.

The increase in length = ·036 inch = ·003 foot.

The original length = 1·5 foot.

The increase in length for 1 foot for $100° = \frac{\cdot 003}{1 \cdot 5}$ foot $= \cdot 002$ foot, and the increase in length for 1 foot for $1° = \cdot 00002$. If we divide the increase in length by the original length and then divide by the number of degrees $\left(\frac{\cdot 003 \text{ foot}}{1 \cdot 5 \text{ foot}} \div 100\right)$, the same numerical result is obtained; in the latter case the result is merely a ratio. This number is called the coefficient of linear expansion; the coefficient of expansion for 1° is a number obtained by dividing the increase in length for 1° by the original length.

The COEFFICIENT OF LINEAR EXPANSION *for* 1° *is the ratio of the increase of length when the temperature is raised one degree to the original length.*

EXAMPLES. VI.

Find the coefficient of expansion in the following examples:—

1. A rod of brass at 15° C. measures 2 feet, at 95° C. it measures 2·003 feet.
2. A rod of glass at 10° C. measures 5 feet, at 70° C. it measures 5·0024 feet.

The coefficient of expansion is numerically equal to the increase in length of a rod of unit length (1 yard, 1 foot, 1 metre), when its temperature is increased 1°.

It is assumed that the coefficient of expansion for 1° is the same at whatever temperature the measurements are made; this is practically true, although there is a slight increase in the coefficient of expansion as the temperature rises.

14.

A bar of zinc measures 2 feet 3 inches at 52° F. and 2 feet 3·07 inches at 212° F. Find the coefficient of linear expansion.

The elongation for $(212 - 52)°$ F. $= \cdot 07$ inch

$\therefore$ „ „ „ $1°$ F. $= \frac{\cdot 07}{160}$ „

$\therefore$ coefficient of expansion $= \frac{\cdot 07}{160}$ inch $\div 27$ inches $= \cdot 000016$.

The coefficient of expansion for 1° C.

$$=\frac{\cdot000015\times9}{5}=\cdot000029.$$

TABLE OF COEFFICIENTS OF LINEAR EXPANSION for 1° C

Glass . .	$=\cdot0000085$	$=$	$\frac{1}{120000}$.
Platinum .	$=\cdot0000085$	$=$	$\frac{1}{120000}$.
Cast iron .	$=\cdot00001$	$=$	$\frac{1}{100000}$.
Wrought iron .	$=\cdot000012$	$=$	$\frac{1}{85000}$.
Copper . .	$=\cdot000017$	$=$	$\frac{1}{58000}$.
Lead . .	$=\cdot000028$	$=$	$\frac{1}{35000}$.
Zinc . .	$=\cdot00003$	$=$	$\frac{1}{34000}$.

This table is only approximate; different specimens vary in their expansions. It assumes that the expansion from 0° to 1° C. is $\frac{1}{100}$ of the expansion from 0° to 100°; this is nearly true, and it is by measuring the expansion for 100° or some such range of temperature that the coefficient is generally calculated. Calculate the above table for 1° F.

15.

A cast-iron tube is 6 feet long in winter when the thermometer is at freezing-point: what will be its length on a summer day when the temperature is 27° C.?

Coefficient of linear expansion of cast iron $=\cdot00001$,
the increase in length of 1 foot for 1° $=\cdot00001$ foot,
$\therefore$ " " 1 foot for 27° $=\cdot00027$ "
$\therefore$ " " 6 feet for 27° $=\cdot00162$ "
$\therefore$ length at 27° C. $=6\cdot00162$ feet.

A copper bar measures 5 metres at 50° C.; what will it measure at – 10° C.?

Coefficient of expansion of copper = ·000017.
The bar cools through 60° C.

$\therefore$ 1 metre shortens ·001020 metre
$\therefore$ 5 „ „ ·0051 „
$\therefore$ length at – 10° C. = 4·9949 metres.

[NOTE.—If the coefficient of linear expansion be given at 0°, the accurate method of working the above examples would be by first calculating the ratio of the lengths at two different temperatures.

Thus, taking the last example,

1 metre at 0° will measure $1 + (\cdot000017 \times 50)$ at $50° = 1\cdot00085$
1 metre at 0° will measure $1 - (\cdot000017 \times 10)$ at $-10° = \cdot99983$
$1\cdot00085 : 5 :: \cdot99983 : x$
x = length at $-10°$ C. = 4·994904 metres.

This method is unnecessary in the case of solids save in very accurate calculations.]

EXAMPLES. VII.

1. Explain what you mean when you say that the coefficient of linear expansion of iron is 0·000012. If an iron yard measure be correct at the temperature of melting ice, what will be its error at the temperature of boiling water?

2. From London to Edinburgh is 400 miles. Suppose the hottest day in summer to be 90° F. above the coldest day in winter; find the difference in length in the rails laid on the railway.

3. A rod of brass just fits between two supports; ice-cold water is poured over it and the bar falls. Why is this? The bar is now heated in a boiler and is found to be too long. Why?

4. A rod of zinc measures 1 ft. 3 in. at 0° C.; what will it measure at 6° C.?

5. A rod of lead, 6 feet long, was fixed between two firm supports on a day in winter when the thermometer was 24° F. It was examined later in the year and was found bent. Explain why. What allowance should have been made so as to avoid buckling when the temperature is 100° F.?

6. Telegraph wires sag more in summer than in winter. Why? Suppose the distance between two posts to be 80 yards and the wire to be made of copper, what change would there be in the length when the thermometer was at 0° C. and 20° C.?

16. THE COEFFICENT OF SQUARE EXPANSION FOR 1°

$$=\frac{\text{increase in area for } 1^\circ}{\text{original area}}.$$

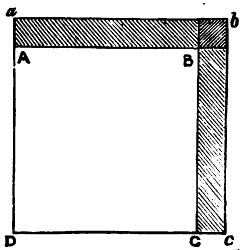


FIG. 10.

Suppose ABCD to be 1 square foot, and that the linear expansion of the solid for 1° be represented by A*a*; then as the square expands *abc*D will be the area after expansion, if there be no reason why the body should expand more in one direction than another.

Let the coefficient of linear expansion be δ;

$$Dabc = ABCD + \text{twice strip } aB + \text{small square } Bb.$$

Strip *a*B is 1 foot long and δ foot wide; its area $= \delta$ square foot.

$$\text{Square } Bb = \delta \times \delta = \delta^2 \text{ square foot};$$

$$\therefore Dabc = (1 + 2\delta + \delta^2) \text{ square foot.}$$

If δ be very small compared with 1 foot, by saying

$$Dabc = (1 + 2\delta) \text{ square foot, a very small error will be made.}$$

Then coefficient of square expansion for 1°

$$= \frac{2\delta \text{ square foot (increase)}}{1 \text{ square foot (original area)}} = 2\delta;$$

that is, twice the coefficient of linear expansion.

Zinc has the greatest coefficient of expansion among the ordinary metals.

A square of zinc 1 foot side on being heated expands so that its side becomes 1·00003 square foot;

$$\therefore \text{new area} = (1{\cdot}00003)^2 = 1{\cdot}0000600009 \text{ square foot.}$$

By neglecting δ^2 the amount ·0000000009 square ft. is neglected, an amount far too small to be noticed.

EXAMPLES. VIII.

1. Write out a table of the coefficients of square expansion.

2. A square brass plate has 2 feet side at 0° C. Find its area at 15° C. Coefficient of linear expansion of brass = ·000019.

3. A square of glass fits tightly into a frame in winter. On a warm day it suddenly cracks. Why?

17. THE COEFFICIENT OF CUBICAL EXPANSION *is the ratio of the increase of the volume of a substance for 1° to the original volume.*

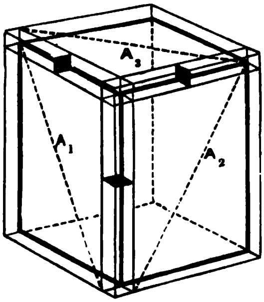


FIG. 11.

Imagine a cube of 1 foot side (cube with thick lines); if it expand so that each side becomes $(1+\delta)$ foot, its volume becomes $(1+\delta)^3$ cubic foot.

The cube after expansion is made up of the original cube + 3 square slabs (A_1, A_2, A_3 are the diagonals) having bases of 1 square foot and each a thickness of δ foot, each on one face of the original cube + 3 strips (a section of each is shown), each 1 foot long, and a base δ^2 square foot + the small cube, whose side is δ foot; ∴ volume after expansion $= (1+3\delta+3\delta^2+\delta^3)$ cubic foot. The small cube δ^3 and the three strips are small compared with the original cube, and if δ be very small these quantities can be neglected and we can write,

$$\text{Volume after expansion} = 1+3\delta,$$

$$\therefore \text{ coefficient of cubical expansion} = \frac{3\delta \text{ cubic foot}}{1 \text{ cubic foot}} = 3\delta$$

$$= \text{three times the coefficient of linear expansion.}$$

To test whether this can be accepted in the case of the cubical expansion of solids :—

$$1 \text{ foot of zinc at } 0° = 1{\cdot}00003 \text{ foot at } 1°,$$

$$\begin{aligned} \therefore \text{ a cube 1 foot side at } 0° &= (1{\cdot}00003)^3 \text{ foot at } 1° \\ &= 1{\cdot}000090002700027 \text{ cubic foot} \\ &= 1{\cdot}00009 \text{ nearly} \\ &= 1+({\cdot}00003 \times 3); \end{aligned}$$

by neglecting the small square ·000000000000027 is neglected,
" " three small strips ·0000000027 " "
both quantities being very small compared with one cubic foot;

∴ coefficient of cubical expansion of zinc

$$= \frac{\cdot 00003 \times 3}{1} = \cdot 00009,$$

or three times the coefficient of linear expansion.

The coefficients of cubical expansion obtained by other methods agree with the number obtained by multiplying the coefficient of linear expansion by 3.

EXAMPLES. IX.

1. Make a table for the coefficients of cubical expansion from the table in § 14.

2. The coefficient of linear expansion of copper is ·000017, a cube of copper of 1 ft. side at 0° C. has a volume of $1 + (3 \times \cdot 000017)$ cubic foot nearly at 1°; what error is made?

3. Suppose a substance has a coefficient of linear expansion ·1; should we be justified in saying the coefficient of cubical expansion was ·3? Why not?

4. A glass vessel contains 120 cubic inches at 0°. Find its volume at 100° C.

5. A cube of copper measures 1 ft. side at 15° C. Find its volume at 180° C.

6. Water pipes are fitted by telescopic joints. Why?

7. What would be the effect of fixing firmly the ends of furnace bars?

8. A glass bottle holds when quite full at the temperature of melting ice 20 cubic inches of ice-cold water. How many cubic inches of boiling water will it hold, the bottle as well as the water being at 100° C.? (Coefficient of linear expansion of glass = ·000009.)

18. THE EXPANSION OF LIQUIDS.

It is only possible to measure the expansion in volume; that is, the cubical expansion.

The expansion of the liquid in Chap. I. § 4 evidently was less than the real expansion, as the expansion of the glass caused the column to stand lower in the tube than it would have stood if the glass had not expanded. Generally the apparent expansion of a liquid is measured.

Real expansion = apparent expansion + expansion of the vessel.

To Find the Apparent Expansion of a Liquid.

In order to find the apparent expansion of a liquid, a thermometer tube is taken, whose capacity up to a certain division on the stem, and also the capacity of any length of the stem, is known at a particular temperature. The tube is filled with the liquid at this temperature to an observed division, and the volume calculated. It is now placed in a bath, heated to an observed temperature; the rise is noticed, and the increase in volume ascertained.

$\left(\dfrac{\text{Increase in volume}}{\text{original volume}}\right) = $ coefficient of apparent expansion for a given number of degrees.

Instead of measuring the volume the following plan is followed :—

Close one end of a piece of glass tubing 8″ long, ¾″ wide; draw out the other end and bend it as in fig. 12, leaving a very fine hole; weigh it, warm the bulb with the point dipped into mercury; on cooling, the mercury enters. Repeat this; ultimately boil the mercury; when the tube cools it will be filled with mercury. Let it cool down to the temperature of the room, the point dipping into mercury; weigh again.

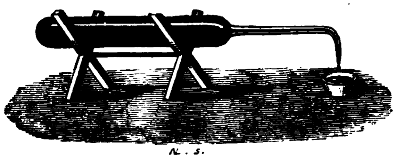


Fig. 12.

Make a cage of open wire gauze to contain the tube, and place it in a steam bath, catching the mercury that is forced out in a weighed capsule; when no more is forced out, let it cool and weigh.

Example.

$$\begin{aligned} \text{At } 15^\circ \text{ C., tube} + \text{mercury} &= 192 \cdot 3 \text{ grams,} \\ \text{tube} &= \underline{\ 15 \cdot 6\ } \text{ grams;} \\ \therefore \text{ weight of mercury} &= 176 \cdot 7 \text{ grams.} \\ \text{At } 100^\circ \text{ C., tube} + \text{mercury} &= 190 \cdot 0 \text{ grams,} \\ \text{tube} &= \underline{\ 15 \cdot 6\ } \text{ grams,} \\ \therefore \text{ weight of mercury} &= 174 \cdot 4 \text{ grams;} \end{aligned}$$

$\therefore$ 174·4 grams of mercury at 15° expand so as to occupy, at 100°, the volume of 176·7 grams at 15°, $\therefore$ expansion for 1 gram $= \frac{2{\cdot}3}{174{\cdot}4}$;

$\therefore$ coefficient of apparent expansion $= \frac{2{\cdot}3}{174{\cdot}4 \times 85} = {\cdot}000153$.

The above instrument is called a weight thermometer, because from the weight of mercury expelled the temperature can be calculated.

[The coefficient of the absolute expansion of mercury has been found, by a method that will not be explained here, to be about $\frac{1}{5550}$ or ·00018.

In the above example, since

Absolute expansion = apparent expansion + expansion of the vessel, the coefficient of expansion of glass = ·00018 – ·000153

= ·000027.

That is, by using the coefficient of absolute expansion of mercury and measuring the coefficient of apparent expansion, the coefficient of expansion of glass can be calculated. By experimenting with any other liquid in this glass vessel we can find the coefficient of apparent expansion of the liquid; then

$$\left.\begin{matrix}\text{coefficient of absolute}\\ \text{expansion of the}\\ \text{liquid}\end{matrix}\right\} = \left.\begin{matrix}\text{coefficient of apparent}\\ \text{expansion of the}\\ \text{liquid}\end{matrix}\right\} + \begin{matrix}\text{coefficient of}\\ \text{expansion}\\ \text{of glass.}\end{matrix}$$]

EXAMPLES. X.

1. What is meant by the real or absolute expansion, and what by the apparent expansion of a liquid? Which is the greater, and why? The coefficient of expansion of mercury being $\frac{1}{5550}$, and its coefficient of apparent expansion in a glass vessel being $\frac{1}{6480}$, find the coefficient of cubical expansion of glass.

2. By using a weight-thermometer, the coefficient of apparent expansion of glycerine was found to be ·000488. The expansion of glass had been previously found to be ·000027. Find the coefficient of absolute expansion of glycerine.

19. Peculiarity in the Expansion of Water.

Take the apparatus shown in fig. 3; heat the flask until the water runs out at the top, then place it in a mixture of ice and observe the movement of the fluid in the tube as it cools. There is a gradual descent for some time, then an ascent, and ultimately it remains

stationary. Remove the flask and place it in warm water; the reverse takes place—a descent, then an ascent.

The meaning evidently is that water, in cooling, contracts to a certain temperature and then expands; that is, a cubic inch of water will weigh more at some temperature above freezing-point than a cubic inch at any other temperature. The mass of a unit volume is called the density of the substance. Then the density of water at this particular temperature is greater than at any other temperature. This temperature, at which water has its maximum density, has been determined to be 4° C. or 39·2° F.

Repeat the above experiment by placing a thermometer through the cork, and when the water is at 0° C. place all in ordinary water, and notice the indication of the thermometer when the water is at its maximum density.

Ice floats in water; therefore ice, bulk for bulk, is lighter than water, that is, water expands on freezing.

Melt paraffin in a test tube; throw pieces of solid paraffin in: the pieces sink; therefore paraffin contracts in freezing (solidifying).

EXAMPLES. XI.

1. What is meant by the density of ice-cold water? Does the density of ice-cold water change when the water is warmed, and, if so, in what way? By what experiment would you find out whether any change in density occurs under these circumstances?

2. How would you show that brass expands when heated?

20. RESULTS OF THIS BEHAVIOUR OF WATER.

In winter the surfaces of ponds and lakes lose heat. The surface water being, bulk for bulk, heavier than that below, sinks; this goes on until the whole pond is at 4° C. The surface water cools, but it is now less dense than the water below; it therefore floats, its temperature falls until it freezes, and the ice, as we know, floats. If water were like paraffin or iron, the surface water would, down to freezing-point, be heavier than the deeper water; thus the whole pond would be reduced to 0° C., a temperature that would destroy much of

the animal life that now exists at 4° C. If it still contracted on freezing, layer after layer of ice would sink, until the whole pond would be a mass of ice.

21. Force of Expansion and Contraction.

Solids and liquids not only expand and contract, but they do work in so doing.

AB is an iron bar passing through sockets in a strong cast-iron frame, CD. The iron bar has a hole at one end, through which passes a small rod, F, of cast iron. At the other end is a screw-thread on which a nut, N, with two arms, works. The rod is heated, placed in its socket, the rod F inserted, and the nut screwed up tightly. As the temperature falls, the bar contracts, and the force is sufficient to break the rod of cast iron.

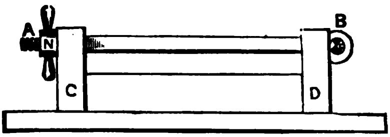


FIG. 13.

Draw out a test-tube; when cool fill it with water, and close the end by a small flame. Wrap it in iron gauze or flannel; place it in a jug of warm water. The water expands with sufficient force to break the glass.

The force exerted is enormous; an iron rod 1 square inch in section in cooling through 9° C. would exert a force of 1 ton.

22. Effects of Expansion and Contraction of Solids.

Walls that have bulged out have had iron bars placed so that they passed across the building through the walls; at each end a nut was screwed close up to the wall: alternate bars were heated; they expanded and the nuts were screwed up further (see experiment in last section). On cooling the force was sufficient to pull the walls closer together; the other bars were now heated, the nuts screwed up, and the bars allowed to cool. By this means the walls were restored to their vertical position.

The iron tyres of wheels are placed on red-hot and fit loosely; on cooling they secure tightly the woodwork. The case of iron bridges and iron rails has been referred to.

Compare in § 14 the coefficients of expansion of glass and of platinum. Place a piece of platinum wire in a fine opening in a glass tube; heat until the glass softens and closes round the platinum; when it cools the joining is perfect, because the coefficients of expansion are the same for the two bodies. Try the experiment with an iron wire or a brass wire.

23. Compensating Pendulums.

Any alteration in the length of the pendulum affects the time of the clock. But, as solids expand and contract, if accuracy be needed, a plan must be devised to keep the length of the pendulum constant. Pendulums so constructed that they do not alter their number of swings per second as the temperature changes are called compensating pendulums. The principal kinds are :—

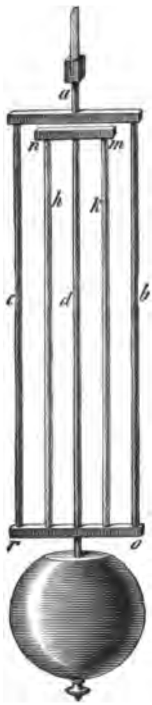


Fig. 14.

1. *Graham's.*—The 'bob' consists of a glass vessel containing mercury. If the temperature increases the rod expands. The mercury also expands and rises in the vessel. They are so arranged that the distance of the centre of oscillation from the point of suspension does not change.

2. *Harrison's Gridiron Pendulum.* — *a*, *b*, *c*, *d* are rods of steel ; *h*, *k* are brass. If the temperature rise, *a*, *b*, *c*, and *d* expand and force the 'bob' farther from the point of suspension. *h* and *k*, in expanding, lift the crosspiece *n m*, and thus lift the 'bob.' *d* passes freely through a hole in *r o*. The result is that *h*, *k* compensate the effect of *a*, *b*, *c*, *d*.

Coefficient of linear expansion of brass
$= \cdot 000019$.

Coefficient of linear expansion of steel
$= \cdot 000011$.

Then the length of brass should be to the length of steel

as 11 : 19, if they are to compensate each other. c and b act like one rod, as also do h and k;

$$\therefore \frac{a+c+d}{h} = \frac{19}{11}.$$

If h equal 11 units, $c = 11+$, it is evident that d must be less than 11. In fact the figure illustrates the principle, but it is not the figure of a real compensating pendulum: more bars are needed. As an exercise construct a compensating pendulum with 5 steel and 4 brass rods.

24. The Balance Wheel.

Solder a strip of brass and a strip of zinc together; hammer them until they are straight.

Heat the compound bar; it bends, the brass being on the concave side.

Coefficient of expansion of brass = ·000019.
" " zinc = ·000030.

The zinc expands more than the brass, and therefore forms the convex side of the bend.

The rate of a chronometer depends upon the mass of the balance wheel, and the distance of the circumference from the centre. The parts B C are made up of a compound strip like the above, the metal having the highest coefficient of expansion on the outside (fig. 15).

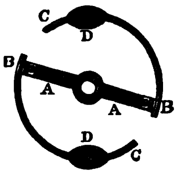


Fig. 15.

When heated the radius A expands, and the chronometer would lose time; but as the heat also causes the strips B C to curve inwards, the masses D are brought nearer the centre, and this compensates for the extension of A, A.

Solids, as a rule, expand as they are heated; stretched india-rubber is an exception. It contracts when heated.

Examples. XII.

1. A pond is just about to freeze; will the surface water or the water at the bottom be the warmer? Why?

2. How would you find the apparent expansion of oil?

3. Describe what takes place when a cubic foot of water is cooled down from 30° C. to 0° C. Draw it at its most important temperatures.

4. Explain how to determine the coefficient of apparent expansion of a liquid contained in a glass bulb.

5. Describe a way of showing the unequal linear expansions of solids by heat. Explain how this unequal expansion is made use of in the gridiron pendulum.

6. The rim of the balance-wheel of a watch is made up of rings of two different metals, one outside the other, and is cut at two points; explain how it is possible for the rate of the watch to be the same in hot and cold weather.

7. Two iron bottles are filled with water at 4° C. and plugged. One is placed in warm water, the other in a mixture of ice and salt. What takes place in both cases? Why?

8. Draw two vertical lines, 12″ apart, to represent rods: one, 12″ long, is copper; the other, 17″ long, is wrought iron. Join the tops, measure the distance, and determine how this distance would change as the rods are heated.

9. Explain how to construct a seconds pendulum which shall keep correct time in hot or cold weather.

10. Describe a gridiron pendulum made of zinc and iron bars. What is the ratio between the lengths of the bars of the two metals?

CHAPTER III.

THE PRESSURE OF THE ATMOSPHERE—THE EXPANSION OF GASES.

25. To Measure the Pressure of the Atmosphere.

Fill a bottle with water; place a piece of paper over the mouth, and press it firmly to the bottle with the hand: invert the bottle and remove the hand; the water does not run out. The pressure of the

Fig. 16.

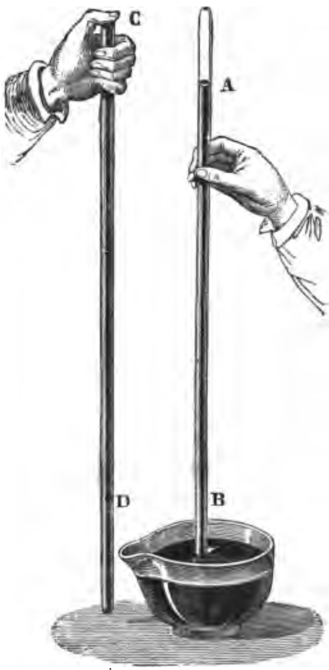


Fig. 17.

atmosphere is greater than the pressure of the mass of water. This atmospheric pressure is exerted in all directions; in the experiment it acts upwards. Repeat the experiment, using a tumbler and a sheet of cardboard (fig. 16). Attempts to perform the experiment when air is in the vessel fail.

Torricelli's Experiment.—Take a clean tube $\frac{1}{4}$ inch internal bore, 32 inches long, and close one end. Fill it with clean dry mercury, place one thumb over the end, and invert in a dish of mercury (fig. 17). The space above the mercury is filled with the vapour of mercury. Measure the height of the mercury in the tube above the mercury in the vessel; in an experiment it was 30 inches. By a principle of hydrostatics the pressure of 30 inches of mercury is supported by the pressure of a column of the atmosphere, whose height is the height of the atmosphere, and whose base is the same area as the base of the tube.

Suppose the section of the tube to be 1 square inch; the pressure of the atmosphere in lbs. on 1 square inch = the pressure of 30 cubic inches of mercury on 1 square inch.

1 cubic inch of mercury weighs 0·49 lb.;

$\therefore$ the pressure of the atmosphere in lbs. per square inch $= 30 \times 0{\cdot}49$ lbs. $= 14{\cdot}7$ lbs. per square inch.

The height of the column of mercury changes as the pressure of the atmosphere changes.

This instrument is called a BAROMETER.

Notice the meaning given to the expression 'a pressure of 30 inches of mercury.'

If water were used instead of mercury, the water would *leave* the top of the tube when the tube was more than $(30 \times 13{\cdot}6)$ inches high, 13·6 being the specific gravity of mercury.

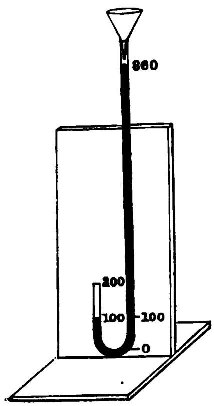


FIG. 18.

26. THE EFFECT OF VARYING PRESSURE ON A GAS.

Close one end of a tube $\frac{1}{4}$ inch bore, 50″ long, and bend it as in fig. 18; the short limb should be about 7 inches. Fasten the tube to a vertical board. Place a small funnel in the open end. Pour a little mercury down, so that it stands the same height in both limbs. A portion of air in the short limb is cut off

from the external air; it is at the pressure of the atmosphere, because the mercury is the same height in each limb. With the barometer carefully measure what this pressure is. Measure the height of the air in the short limb, adjust a millimetre scale to both limbs so that o is on a level with the mercury. Pour mercury into the funnel; after a minute measure the height in the short limb, also the height of the mercury in the long limb above the level in the short limb. The air in the short limb is now subject to a pressure of the atmosphere together with the pressure of this last measured height of mercury. Make several measurements in millimetres.

	V Volume	(*a*) Pressure of Mercury	(*b*) Barometer Pressure of Atmosphere	Total Pressure (*a*+*b*)	V×P
1	221	143	756	899	198,679
2	176	378	"	1134	199,584
3	112	1023	"	1779	199,248
4	102	1200	"	1956	199,512
5	95	1346	"	2102	199,690
			Average		199,428

In number 3 the volume is about one half of number 1. The pressure is about twice the pressure in number 1. In halving the volume the pressure has been doubled. In each case multiply the volume by the total pressure; the result is in the fifth column.

Allowing for errors of experiment, we obtain the law:

In a gas, when the temperature is constant the product of volume and pressure is a constant.

Or, *the volume varies inversely as the pressure.* This is known as BOYLE'S or MARRIOTTE'S LAW.

The volume was treated as a height. It was of course understood that the volume was height × area of section of tube. As the tube was of uniform bore, the volume was proportional to the height.

The law also holds good when the pressure is less than that of the atmosphere.

To see the reason for the phrase 'temperature is constant,' pour warm water over the short limb and notice the change.

A gas measures 200 cubic centimetres when the pressure is one atmosphere; what will it measure when the pressure is 5 atmospheres, if the temperature remain constant?

By Boyle's law volume $\times$ pressure $=$ constant. In this case constant is $200 \times 1 = 200$,

$$\therefore \text{ new volume} \times 5 = 200,$$
$$\therefore \text{ new volume} = 40 \text{ cubic centimetres.}$$

The law is similar to the following: Suppose a man with 1,000*l.* amuses himself by purchasing horses at various prices; evidently the number of horses is determined by the price of each horse, that is

Price per horse $\times$ number of horses $=$ 1,000*l.* (a constant).

The weakness of the various thermometers as long as they were open to the pressure of the atmosphere is now evident; the volume of the liquid or gas would change with the change of pressure, and this change would confuse the results of the thermometer as to temperature. (See § 7.)


FIG. 19.

27. THE EXPANSION OF GASES.

Pass a narrow tube 18″ long through a cork, and insert the cork in a 2-ounce flask. Invert the flask as in fig. 19, dipping the tube into a flask of coloured water. Warm the 2-ounce flask so as to expel a little air; the coloured water rises in the tube, and its movements show the effect of change of temperature upon the confined air. The apparatus forms a simple AIR THERMOMETER. It could be graduated by placing a mercurial thermometer near it and noting the position of the water at two temperatures (for example, the temperature of the room and that of a warm cupboard) and dividing the scale accordingly.

Air expands on being heated; by filling the flask with coal

gas, hydrogen, etc., it can be shown that this is true of all gases.

If the volume of the flask and part of the tube filled with air were known, also the volume of any length of the tube, then by observing the distance the water is depressed when the air thermometer is heated, say 5°, we obtain

$$\text{the coefficient of expansion for } 1^\circ = \frac{\text{increase of volume}}{\text{original volume} \times 5}.$$

By experiments with various gases it is found

That all dry gases have the same coefficient of expansion if the pressure remain the same.

Like Boyle's law and other laws deduced from experiment this is not exactly true, but it is sufficiently true for all ordinary purposes if the temperature do not greatly exceed 100° C.

Experiments have shown that this law, called CHARLES' law, may be written :

In any dry gas, whatever the pressure may be, the volume is increased $\frac{1}{273}$ *of its volume (or* ·003665) *for every increase of one degree Centigrade of temperature, always measuring from freezing-point.*

28. ABSOLUTE TEMPERATURE.

[The regular expansion of dry air (or gas) has suggested its use as a thermometric substance; the objection to it is that corrections must be made for the barometric changes. If two air thermometers were constructed so that they agreed at 0° and 100° and were then graduated, they would agree at any intermediate temperature ; this would not be the case with a mercurial and an alcohol thermometer.

By Charles' law if the freezing-point on an air thermometer be 273 inches above the bottom of a uniform tube, at a temperature of −16° the index would be 213 inches from the bottom, and evidently at a temperature of −273° the index would touch the bottom. It is never expected that this temperature will be reached, nor is it probable that the air or gas would remain as a gas. It is convenient to call this temperature (−273° C.) the ABSOLUTE ZERO of the air thermometer, and temperatures measured from this zero are called ABSOLUTE TEMPERATURES. The absolute temperature is obtained by adding 273 to the reading on the Centigrade scale.]

Examples. XIII.

1. State the law governing the expansion of a gas at constant temperature under varying pressures, and show how the law may be proved experimentally.

2. Fifty cubic feet of air are enclosed in a cylinder, the pressure on the piston being 200 lbs. weight; 800 lbs. more are added: find the new volume, supposing that the temperature remains constant.

3. A gas measures 320 cubic cm. under a certain pressure; the pressure is trebled. Find the new volume (temperature constant). Why are the words in brackets inserted?

29. The Fire Syringe.

Dip a little cotton wool in a few drops of carbon disulphide, and place it in the fire syringe; shake it in the tube a few times, insert the piston, and compress the imprisoned air suddenly; a flash is seen, showing that heat has been evolved. German tinder may be ignited in the same way.

Clean the tube thoroughly and insert a piece of cotton wool moistened with water; push the piston down and allow it to stand for a few minutes; withdraw it suddenly; the air expanding cools, and moisture is deposited.

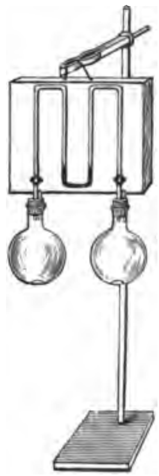


Fig. 20.

If a gas be suddenly compressed its temperature rises; if it be suddenly rarefied the temperature falls.

In the experiments upon Boyle's law, the gas is compressed slowly and the heat is allowed to escape before the reading is taken.

30. Leslie's Differential Thermometer.

Fit two 2-ounce flasks each with a good cork, each cork having two holes. A piece of glass tubing 24″ long is bent as in fig. 20; coloured water is drawn into the bend, and the tube is inserted in the corks. A glass stopper is placed in each of the other holes. By using these stoppers arrange that the liquid stands the same height in each limb. Fasten the thermometer to a board.

If one bulb be subject to a greater temperature than the other, the index of coloured water moves. Affix a scale and call the level of the water in each limb o. Place the bulbs in two baths of water, one 5° higher than the other; call the position of the water 5, and divide the scale between o and 5.

The thermometer does not indicate the actual temperature; it shows *differences* of temperature and is very sensitive.

31. Examples of Charles' Law.

One cubic inch of a gas at 0° becomes

$$\left(1 + \frac{1}{273}\right) \text{ cubic inch at } 1°,$$
$$\left(1 + \frac{10}{273}\right) \text{ cubic inch at } 10°,$$
$$\left(1 + \frac{56}{273}\right) \text{ cubic inch at } 56°;$$

or 273 cubic inches of gas at 0° become

274	cubic inches at	1°,
283	,, ,,	10°,
329	,, ,,	56°.

A gas measures 160 cubic metres at 0° C.; what will it measure at 15° C. if the pressure remain constant?

273 cubic inches at 0° C. become 288 cubic inches at 15° C.;

$\therefore$ 160 cubic inches become $\dfrac{160 \times 288}{273} = 168{\cdot}8$ cubic inches.

A gas measures 1000 litres at 15° C.; find the volume at 27°.C. if the pressure remain constant.

273 cubic inches at 0° C. become 288 cubic inches at 15° C. and 300 cubic inches at 27° C.;

$\therefore$ 288 cubic inches at 15° C. become 300 cubic inches at 27° C.;

$\therefore$ 1000 litres at 15° C. become $\dfrac{1000 \times 288}{277}$ cub. ins. at 27° C.

Examples. XIV.

1. 180 cubic inches of hydrogen are measured at 0°; what will be the volume at 15° C. if the pressure be constant?

2. 250 cubic feet of air are measured at 15° C.; what volume will it occupy at 20° C., pressure constant?

3. State Boyle's law. A given quantity of air occupies a volume of 600 cubic inches at a temperature of 20° C.; find the volume which the air will occupy at 100° C., supposing the pressure to remain constant. (The coefficient of expansion of air is ·003665.)

32. The Effect of Heat on the Density of Substances.

The density of a body is the mass of unit volume.

One cubic inch of water at 60° F. weighs 253 grains. The density of water is 253 when an inch and a grain are the units. One cubic centimetre of water at 4° C. weighs one gram.

If 1 c.cm. of water at 4° be heated to 100°, its volume becomes 1·043 c.cm. Its mass has not altered, that is, there is the same quantity of matter.

$$\therefore \text{ at } 100^\circ \text{ C. } 1{\cdot}043 \text{ c.cm. weighs } 1 \text{ gram};$$

$$\therefore \text{ at } 100^\circ \text{ C. } 1 \text{ c.cm. weighs } \frac{1}{1{\cdot}043} \text{ gram} = {\cdot}86 \text{ gram};$$

$$\therefore \text{ the density of water at } 100 \text{ is } {\cdot}86 \text{ gram.}$$

Knowing the coefficient of expansion, the density at any temperature can be calculated.

Worked Examples.

If one cubic foot of zinc at 0° C. weighs 6900 ounces, find the weight of 1 cubic foot of zinc at 100° C.

The coefficient of linear expansion of zinc = ·00003;

$$\therefore 1{\cdot}00009 \text{ cubic ft. at } 100^\circ \text{ weighs } 6900 \text{ ounces};$$

$$\therefore 1 \text{ cubic foot at } 100^\circ \text{ weighs } \frac{6900}{1{\cdot}00009} \text{ ounces};$$

$$\therefore \text{ density at } 100^\circ = 6899{\cdot}4 \text{ ounces.}$$

The difference for 100° is so small $\left(\frac{1}{11500}\right)$ that it can generally be neglected in the case of all metals, zinc having the highest coefficient of expansion among the metals.

In liquids the coefficient of expansion is greater, and frequently the effect of temperature on the density has to be taken into account.

Seven cubic feet of water at 4° C. weigh 7000 ounces; what will the same volume weigh at 100° C., the coefficient of dilatation of water between 4° and 100° being ·043?

7 cubic feet at 4° become $(7 \times 1{\cdot}043)$ cubic feet $= 7{\cdot}301$ at 100°;

$$\therefore \text{ 7 cubic feet at } 100° \text{ weigh } \frac{7000 \times 7}{7{\cdot}301} = 6711 \text{ ounces.}$$

100 cubic inches of air at 0° C. weigh 31 grains; what will the same volume weigh at 90° C.?

The coefficient of expansion of gases always measured from $0° \text{ C.} = \frac{1}{273} = \frac{11}{3000}$ nearly $= {\cdot}00367$.

$$100 \text{ cubic inches at } 0° = 100\left(1 + \frac{11 \times 90}{3000}\right) \text{ cubic inches}$$

$$= \frac{3990}{30} \text{ cubic inches at } 90°;$$

$$\therefore \text{ 100 cubic inches at } 90° \text{ weigh } \frac{31 \times 100}{\frac{3990}{30}} \text{ grains}$$

$$= \frac{31 \times 100}{133} \text{ grains}$$

$$= 22{\cdot}3 \text{ grains.}$$

One litre of a gas weighs 2 grams at 100° C.; find the weight of a litre of the gas at 10°, if the pressure has not changed.

$(273+100)$ litres at 100° C. become $(273+10)$ litres at 10° C.

$$\text{1 litre at } 100° \text{ C. becomes } \frac{1 \times 283}{373} \text{ at } 10°.$$

$$\text{1 litre at } 10° \text{ weighs } \frac{2 \times 373}{283} \text{ grams}$$

$$= 2{\cdot}7 \text{ grams.}$$

Examples. XV.

1. 50 cubic inches of a gas weigh 16 grains at 0°; what will the same volume weigh at 80° C.?

2. 11·16 litres of oxygen weigh 16 grams at 0° C.; what will 10 litres weigh at 15°, pressure constant?

33. THE EFFECT OF CHANGE OF PRESSURE ON THE DENSITY.

In both liquids and solids the effect of change of pressure is so small in changing the volume that it need not be considered. In gases the coefficient of expansion is high, and also change of pressure produces change of volume (Boyle's law).

One litre of carbonic acid weighs 1·8 gram when the pressure is 1 atmosphere. Find the weight of 1 litre when the pressure is 2 atmospheres. Temperature constant.

Its weight when the pressure is 2 atmospheres is the same, but its volume is now $\frac{1}{2}$ litre;

$\therefore$ 1 litre at a pressure of 2 atmospheres weighs 3·6 grams.

100 litres of air weigh 129·3 grams at 760 mm. pressure. Find the weight of 100 litres at a pressure of 1000 mm. Temperature constant.

100 litres at 760 mm. pressure become $\frac{100 \times 760}{1000}$ litres at 1000 mm. pressure $= 76$ litres;

$$\therefore \text{ 100 litres weigh } \frac{129{\cdot}3 \times 100}{76} \text{ grams} = 170{\cdot}1 \text{ grams};$$

$$\text{i.e. } \frac{\text{density at 760 mm. pressure}}{\text{,, \quad 1000 \quad ,,}} = \frac{129{\cdot}3}{170{\cdot}1}.$$

100 cubic inches of air weigh 31 grains at 0° C. What will be the weight of the same volume of air at 20° C., and the pressure $\frac{1}{3}$ of its original amount, coefficient of expansion being $\frac{11}{3000}$?

(1) *Effect of Temperature.*—100 cubic inches of air at 0° C. become $100\left(1+\frac{11 \times 20}{3000}\right)$ cubic inches at 20° C.

(2) *Effect of Pressure.*—The pressure being $\frac{1}{3}$ of original pressure, by Boyle's law the volume will be 3 times the original amount;

$$\therefore \text{ new volume} = 3 \times 100\left(1+\frac{11 \times 20}{3000}\right) \text{cubic inches}$$

$$= \frac{3220}{10} = 322 \text{ cubic inches};$$

$\therefore$ 100 cubic inches of air at 20° C. weigh $\frac{31 \times 100}{322}$ grains
$= 9{\cdot}6$ grains.

EXAMPLES. XVI.

The coefficient of expansion of air is $\frac{1}{273}$.

1. If a litre of atmospheric air at the temperature of 0° C., and pressure of 76 centimetres of mercury, have a mass of 1·293 gram, determine the mass of a cubic metre of air measured at the temperature of 50° C. and 50 centimetres pressure.

2. A volume of 64 cubic feet of air under a pressure of 29·4 inches of mercury and at a temperature of 15° C. is heated to a temperature of 100° C., and the pressure is increased to 30 inches; find the resulting volume.

3. What relation exists between the temperature, pressure, and volume of a given quantity of gas? A cubic foot of air at the temperature 100° C. is cooled down to 0°, and at the same time its pressure is halved. Determine its new volume.

CHAPTER IV.

HEAT AS A QUANTITY—SPECIFIC HEAT—CALORIMETERS.

34. The Thermal Unit.

The previous experiments have shown that heat is something that flows from a body at any temperature to a body at a lower temperature. This is analogous to the flow of water from a high level to a lower level. It does not follow that heat is a material substance like water.

Take four beakers, weigh into each a pound of water. In making up the weight in two of the beakers use a few pieces of ice. Note the temperatures; stir the beakers containing ice until the ice has all melted; the temperature will be 0° C. Take one beaker with water at the temperature of the room, say at 16°, and one with water at 0° C. Mix these together and note the temperature—in this experiment 8°.

Warm one of the beakers to about 35° C. Mix this with the other beaker of water in which the ice has all melted; the mixture is at 17·5° C.

1 lb. of water at 0° C. + 1 lb. of water at 16° C. = 2 lbs. of water at 8° C.

1 lb. of water at 0° C. + 1 lb. of water at 35° C. = 2 lbs. of water at 17·5° C.

Take 2 lbs. of water, one at 16° and one at 35° C.; 1 lb. of water at 16° C. + 1 lb. of water at 35° C. = 2 lbs. of water at 25·5° C.

1 lb. of water cooling 8° (from 16° to 8°) raised the temperature of 1 lb. 8° (0° to 8°).

1 lb. of water cooling 17·5° raises the temperature of 1 lb. 17·5°.

1 lb. of water cooling 9·5° raises the temperature of 1 lb. 9·5°.

Similarly by experiment.

1 lb. of water at 0° C. + 2 lbs. of water at 15° C. = 3 lbs. of water at 10° C.

2 lbs. of water cooling 5° heat 1 lb. of water 10°.

2 lbs of water at 0° + 1 lb. of water at 15° = 3 lbs. of water at 5°.

1 lb. of water in cooling 10° heats 2 lbs. of water 5°.

The result is that the quantity of heat that 1 lb. of water gives out in cooling through 1° of temperature = the quantity of heat used in raising 1 lb. 1°; and that it takes 5 times the amount to raise 1 lb. through 5°, and 10 times the amount to raise 2 lbs. through 5°.

The amount of heat required to raise the temperature of 1 *lb. of water from* 0° *C. to* 1° *C. is called* THE THERMAL UNIT.

The unit of mass is 1 lb. and the Centigrade scale is used.

This amount is a quantity that we can add, subtract, multiply, and divide just like any other quantity.

Is a degree of temperature a quantity? can we add degrees together?

Weigh a quarter of a pound of water into a beaker, reducing the temperature to 0° C. by the method given. Weigh a quarter of a pound of gun-shot into a dry flask. Place this flask in a beaker of water kept boiling. Stir the shot and test with thermometer. Its temperature will rise to nearly 100° C. Pour the shot into the cold water and stir, noting the resultant temperature. In an experiment it was 10° C.

$\frac{1}{4}$ lb. of shot cooling 90° raises $\frac{1}{4}$ lb. of water 10°,
∴ 1 „ „ „ 90° „ 1 „ „ 10°,
∴ 1 „ „ „ 9° „ 1 „ „ 1°;

∴ to raise 1 lb. of shot 1° requires $\frac{1}{9}$ the amount of heat required to raise 1 lb. of water 1°.

The ratio of the amount of heat required to raise one unit of mass of any substance 1°, *to the amount of heat required to raise an equal mass of water* 1°, *is called the* SPECIFIC HEAT *of the substance.*

The specific heat of gun-shot is $\frac{1}{8}$
when " " " " water is 1.

The number of thermal units required to raise the temperature of a body 1° is called its capacity for heat;

$$\therefore \frac{\text{capacity}}{\text{mass in lbs.}} \text{ is numerically equal to the specific heat of body.}$$

35. Experiments to Show that Bodies have Different Specific Heats.

Take circles of silver (a florin), copper (a penny), iron, lead, etc., same size and thickness; hold them at the same distance from a bright fire; in one minute test with a thermometer.

Their order as regards temperature is lead, silver, copper, iron.

All have received the same amount of heat; evidently it requires more heat to raise the temperature of copper 1° than it does to raise the temperature of lead 1°. The specific heat of copper is greater than that of lead.

36. Take a saucer half-full of water. Place thirty grams of white bees'-wax in it, and place all in an oven until all the wax is melted; allow it to cool; when it first solidifies cut round the edges; let it stand for a day to harden; remove the wax and place it on a large ring of a retort-stand. Suspend cylinders of lead, bismuth, copper, and iron by a fine wire for some time in boiling oil. Remove and place them on the wax plate. The iron falls through first, followed by the copper; lead and bismuth are unable to struggle through (fig. 21).

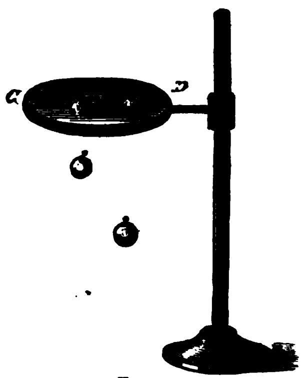


FIG. 21.

The rate at which they pass through depends on (1) density, (2) the amount of heat they give to the wax. Compare iron and lead. The lead is the heavier and has this advantage over the copper. The copper

therefore must give up a greater amount of heat in cooling; its specific heat is higher.

This experiment, for the reason given above, cannot be used to compare the specific heats of bodies.

EXAMPLES. XVII.

1. What is meant by the thermal unit? Write out a definition, using one gram as the unit of mass, and one degree Centigrade.
2. Explain 'specific heat' and 'capacity for heat.'
3. 50 grams of copper at 80° C. are mixed with 57 grams of water at 15°. The temperature after mixing is 20°. Find the specific heat of copper. What is the capacity for heat of the fifty grams?
4. Why should a pound of iron heated to 100° C. sink further into ice than a pound of lead at the same temperature?
5. How many units of heat will be required to raise 6 lbs. of water from 0° C. to 10° C.; 10 oz. of water from 7° C. to 15° C.?

37. METHOD OF MIXTURES.

An instrument for measuring the specific heat of a body is called a CALORIMETER.

TO FIND THE SPECIFIC HEAT OF ZINC.

Take a strip of zinc weighing over $\frac{1}{4}$ lb. Cut it down until it weighs $\frac{1}{4}$ lb. (this is not absolutely necessary; it simplifies the calculation); roll it into a spiral.

Suspend it by a thread in steam, and place a thermometer near to ascertain the temperature. Weigh $\frac{1}{2}$ lb. of water into another beaker, and note its temperature. Move the zinc into this beaker (fig. 22), stir it well in the water, and note the resultant temperature. Calculate as in § 34.

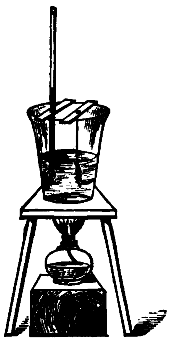


FIG. 22.

This method of finding the specific heat is called the METHOD OF MIXTURES.

The thermal unit will increase as the mass increases; that is, it is greater for 1 lb. than for 1 oz.; it is less for 1 gram than for 1 oz. Again, if we use degrees Centigrade it will be greater than if we use degrees Fahrenheit.

THE SPECIFIC HEAT is a *ratio*, and it evidently will be the same whether we use 1 gram, 1 lb., or 1 oz. as the unit; and whether the degree Centigrade or Fahrenheit be used, provided we use the same units for water and for the substance.

EXAMPLES. XVIII.

1. What is meant by specific heat? If 8 ounces of zinc at temperature 95° C. be put into 20 ounces of water at 15° C. and the resulting temperature be 18° C., what is the specific heat of zinc?

2. What is meant by the statement: the specific heat of water is $10\frac{1}{2}$ times the specific heat of copper? If 15 lbs. of copper at 80° C. be immersed in 18 lbs. of water at 42° C., find the temperature to which the water rises.

3. What is meant by saying that the specific heat of water is 30 times as great as that of mercury? If a pound of boiling water is mixed with a pound of ice-cold mercury, what will be the temperature of the mixture?

4. A ball of platinum whose mass is 200 grams is removed from a furnace and immersed in 150 grams of water at 0°. If we suppose the water to gain all the heat which the platinum loses, and if the temperature of this water rises to 30°, determine the temperature of the furnace.

N.B. The specific heat of platinum is 0·031.

5. What is meant by unit of heat? If the specific heat of iron be $\frac{1}{9}$, and 5 lbs. of iron be cooled down from the temperature of boiling water to the temperature of melting ice, how many units of heat are evolved?

38. DEFECTS OF THE METHOD.

1. Part of the heat is used in heating the beaker.
2. Part is lost by cooling.
3. The metal loses heat in being moved.
4. Heat is used in heating the thermometer.

[*To Correct for No.* 2.—Cover the outside with felt; this prevents loss by conduction; or make the calorimeter of thin polished copper and suspend it by fine threads inside a polished vessel; the heat radiated is reflected back.

To Correct for No. 3.—This requires complex apparatus; and if the experiment be done smartly little heat is lost. Some few drops of water may also come over with the zinc.

Repeat the experiment, covering the calorimeter with felt, or rest it inside another beaker, surrounding it with cotton wool.

To Correct for No. 1.—If the amount of heat used in heating the calorimeter is to be taken into account, we must either know its capacity for heat or its mass and its specific heat.

Suppose the calorimeter to be of glass and that its mass be 10 grams, and that the specific heat of glass be ·2; then it requires $10 \times \cdot 2 = 2$ units of heat to heat the glass 1°. 2 *is called the water equivalent of the calorimeter*, as due allowance will have been made if the 2 grams be added to the weight of the water.

Find the capacity for heat of the calorimeter. Let it stand until its temperature is at that of the room, say 15°, add ¼ lb. of water at 17°; from the cooling calculate the capacity for heat of the calorimeter; similarly find the water equivalent of the thermometer.

A copper calorimeter of specific heat ·095 has a mass of 120 grams, and contains 280 grams of water at 15° C. Find the specific heat of a substance when 375 grams of it at a temperature of 100° C. will, when immersed, raise the temperature of the water to 25° C.

1° *Calorimeter.*—To raise 120 grams 1° requires $(120 \times \cdot 095)$ units of heat $= 11 \cdot 4$ units, i.e. the calorimeter is equivalent to 11·4 grams of water.

$\therefore (280+11 \cdot 4) \times (25-15)$ units of heat are needed, i.e. $291 \cdot 4 \times 10 = 2{,}914$ units of heat. These are obtained from 375 grams cooling 75°.

$\therefore$ 1 gram cooling 1° loses $\dfrac{2914}{75 \times 375}$ unit $= \cdot 259$ unit.

$\therefore$ answer: the specific heat of substance is ·259.]

EXAMPLES. XIX.

1. If a copper ball weighing 6 lbs. taken out of a furnace and plunged into 20 lbs. of water at 10° C. heats the water to 25°, what was the temperature of the furnace? (The specific heat of copper at all temperatures may be taken as ·095.)

2. A ball of copper at 98° C. is put into a copper vessel containing 2 lbs. of water at 15° C., and the temperature of the water, ball, and vessel after the experiment is 21° C.; the weight of the vessel is 1 lb., and the specific heat of copper is ·095; find the weight of the copper ball.

3. What is the specific heat of a substance? The weight of a copper calorimeter is 110 grams, and the specific heat of copper is ·095; 400 grams of water at a temperature of 16° C. are put into a calorimeter, and then 60 grams of the substance which has been heated to 98° C. are placed in the water, whose temperature is now found to be 21° C. Find the specific heat of the substance.

CHAPTER V.

LATENT HEAT OF FUSION—SPECIFIC HEAT—SOLIDIFICATION.

39. Laws of Fusion.

Common experience informs us that heat not only changes the temperature of bodies, but that it also changes their physical condition. By heat solid ice is changed into a liquid, and the liquid into a gas.

Crush ice to small pieces in a mortar; make a spoon of wire gauze; use this to lift the pieces into a beaker; drain from the beaker any water left; place a thermometer in the ice, and apply heat (place the beaker in boiling water). Observe the thermometer.

The ice melts, but the thermometer *does not rise above* 0° C. until every particle has melted. What becomes of the heat?

Take pieces of paraffin (from a candle); place them in a beaker; insert a thermometer; heat on a sand bath.

Again, the thermometer remains stationary when the paraffin begins to melt, until every particle of paraffin is melted. As the result of similar experiments on solids we obtain the laws of fusion.

(1) Every substance begins to melt at a certain definite temperature (if the pressure be constant).

(2) From the time fusion begins till the time it is completed, the temperature remains constant.

The temperature at which a body begins to melt is called its *melting-point*.

TO FIND THE MELTING-POINT OF WAX.

Draw out a piece of glass tubing Cut off 1 inch of the finest part. Close one end. In this place a little wax. Fasten the tube to the thermometer with an india-rubber band. Place in a flask (as in fig. 23).

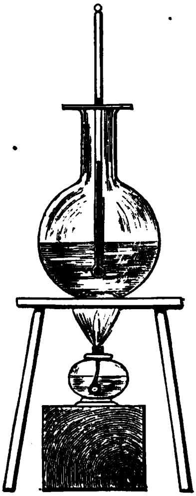


FIG. 23.

Notice—

(*a*) when fusion begins, 49° C. } mean
(*b*) when it ends, 50° C. } $=49\frac{1}{2}$.

Take away the flame; notice—

(*c*) when it begins to solidify, 50° C. } mean
(*d*) when completed, 48° C. } $= 49$.

Melting-point of wax $= \frac{49\frac{1}{2}+49}{2} =$ 49·25° C. For bodies at higher melting-point use sulphuric acid instead of water.

It is evident in these cases that heat is required to melt (fuse) solids. There is also the case when solids dissolve in water or other liquids.

Place one bulb of the differential thermometer in water and observe the position of the index. Add to the water any soluble solid, as sal ammoniac, sulphate of soda.

The index moves, showing that, in dissolving, the solid requires heat. This heat is taken from the water and its temperature falls. By using suitable solids and liquids, the temperature can be lowered sufficiently to freeze the water.

Pour common hydrochloric acid into a beaker, and in the acid place a thin test tube containing a little water; add sulphate of soda to the acid.

Stir with the test tube; the temperature is lowered and the water freezes. Ice machines are made on this principle.

The heat used up in melting solids seems lost; its presence is not indicated by the thermometer. This heat was said years ago to have become latent, and hence was called LATENT HEAT.

It may aid you if you imagine that the heat is engaged in tearing the solid particles asunder, that they may appear in the liquid form, and that until this is done the heat cannot appear as sensible heat and affect the thermometer. Do not form the idea that the heat is hidden away doing nothing.

The amount of heat required to change a ~~unit of~~ mass of a solid into a liquid without raising its temperature is called the LATENT HEAT OF FUSION *of that solid.*

TABLE OF MELTING-POINTS.

Mercury	$-38{\cdot}8°$	Sulphur	114°
Ice	0	Bismuth	264
Butter	$+33$	Lead	335
White wax	65	Iron	1200

40. TO DETERMINE THE LATENT HEAT OF FUSION OF ICE.

Weigh a beaker, add about 50 grams of dry crushed ice, drain off the water, and weigh to obtain the amount of ice.

Pour about 100 grams of boiling water upon the ice, stir until all is melted, and note the temperature. Weigh again to obtain the amount of water added.

Beaker weighed 16·5 grams.

Beaker and ice weighed 66·5 grams, $\therefore$ ice = 50 grams.

Beaker + ice + water weighed 166·5 grams, $\therefore$ water = 100 grams.

The units are 1 gram and 1° Centigrade.

The hot water was at 100°. The final temperature was 40°.

100 grams of water in cooling from 100° to 40° give up (60×100) thermal units = 6000 thermal units.

50 grams of water in heating from 0° to 40° require $(50 \times 40) = 2000$ thermal units.

$\therefore$ 4000 thermal units to account for. They have been used in melting ice at 0° to water at 0°.

∴ it requires 4000 thermal units to melt 50 grams of ice.

∴ the number of units of heat required to melt 1 gram of ice at 0° to water at 0° is 80.

THE LATENT HEAT OF FUSION OF ICE IS 80. If the thermal unit be defined by using 1 lb. and 1° C. as units, and 1 lb. be used as the unit of mass, the result again will be 80.

The same defects are to be noted in the calorimeter as in § 38.

Having determined the latent heat of fusion of ice, the knowledge can be used in other experiments; for every lb. or gram, according to the unit of mass chosen, of ice melted it will be known that 80 thermal units are used.

Remember that ice increases in volume on being heated.

41. TO DETERMINE SPECIFIC HEATS BY THE METHOD OF FUSION.

BLACK'S METHOD.—A hole is cut in a block of ice by using a brace and bit, and an ice-cover is fitted over it; all are wiped dry with a sponge; a piece of metal heated to 100° is quickly placed in the hole, and the cover is replaced. After a short time the metal is taken out and wiped dry with a weighed sponge, which also absorbs all the water in the hole. Thus the amount of ice melted is determined.

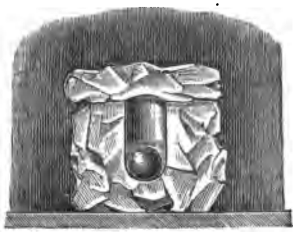


FIG. 24.

EXAMPLE.

A piece of zinc weighing 15 grams was used; the water absorbed by the sponge was 1·8 gram: 1·8 gram of ice in melting requires (1·8 × 80) = 144 units of heat. This has been obtained from 15 grams of zinc cooling from 100° to 0°.

$$\therefore \text{ 1 gram cooling } 1^\circ \text{ gives up } \frac{144}{100 \times 15} = \cdot 096 \text{ unit;}$$

∴ the specific heat of zinc is ·096.

LAVOISIER AND LAPLACE improved the method by using the ICE CALORIMETER.

The body M is placed in a thin copper vessel A; A is placed in a vessel B from which it is separated by ice; B is separated

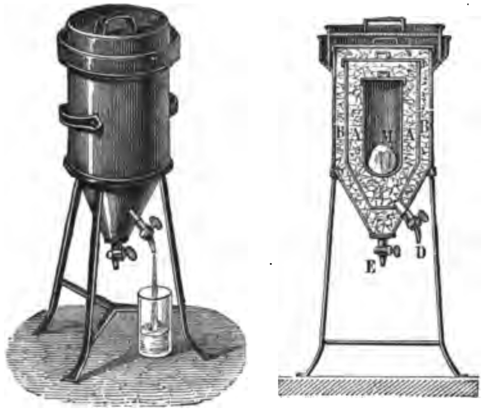


FIG. 25.

from the outer vessel by ice, to prevent the heat of the room melting the ice in A. The water melted runs off by a stop-cock D, is weighed, and the calculation performed as above.

42. THE SPECIFIC HEAT OF LIQUIDS is determined either by using the method of mixtures, or by calculating the amount of ice melted (the ice calorimeter).

TO DETERMINE THE SPECIFIC HEAT OF TURPENTINE.

(*a*) METHOD OF MIXTURES.—Weigh a certain amount of turpentine at the temperature of the room; pour it into a weighed quantity of water at 100° C. Note the resultant temperature, and calculate as in § 37.

(*b*) THE ICE CALORIMETER.—Weigh about 30 grams of turpentine; heat to 70° or 80° C.; pour it into the thin vessel in the ice calorimeter (Lavoisier's), and calculate from the amount of ice melted.

Some liquids on being mixed evolve heat by chemical action; for example, alcohol and water. The specific heat of alcohol cannot therefore be determined by mixing with water.

43. The Specific Heat of Gases

In heating a gas, the gas may be allowed to expand, as it does in the air thermometer, its pressure being that of the atmosphere; or it may be heated in a vessel that does not allow it to expand, when it will be subject to an ever-increasing pressure. Therefore the specific heat of a gas can be calculated at constant pressure, or at constant volume.

Suppose in the air thermometer (fig. 19) the gas has required a certain amount of heat to raise its temperature 5°, and that the index has fallen from the top to the bottom of the tube. Now suppose the index be pushed back to the top of the tube. By the compression the temperature will rise, and the gas will regain its original volume.

Thus the same amount of heat, applied to a gas, will raise its temperature higher if the volume be constant, than if the pressure be constant. That is, the specific heat of a gas at constant pressure is greater than the specific heat at constant volume.

It is found that the specific heat of a gas at constant pressure divided by the specific heat of a gas at constant volume $= 1{\cdot}41$.

Table of Specific Heats.

Specific heat of water = 1.

Solids.		*Liquids.*	
Bismuth	·031	Turpentine	·426
Lead	·031	Alcohol	·062
Mercury	·033	*Gases at Constant Pressures.*	
Zinc	·095		
Iron	·114	Air	·237
Glass	·198	Oxygen	·217
Ice	·489	Water Vapour	·481
		Hydrogen	3·409

Examples. XX.

1. Suppose you have a cubic foot of ice at the melting temperature, and that you gradually apply heat to it. What changes of temperature or volume does it undergo?

2. Describe Black's experiments to determine the latent heat of water.

3. 25 grams of copper at 100° C. are just sufficient to melt 2·875 grams of ice at 0°, so that water and copper are finally at 0°. Find the S. H. of copper.

4. The S. H. of iron is ·113; how many lbs. of iron at 250° C. must be introduced into an ice calorimeter in order to produce 2 lbs. of water?

5. Explain the difference between the specific heat of air at constant pressure and its specific heat at constant volume. Which of them is the greater, and why?

44. Consequence of the High Specific Heat of Water.

'Comparing equal weights, the specific heat of water being 1, that of air is ·237. Hence a lb. of water, in losing one degree of temperature, would warm 4·2 lbs. of air one degree. But water is 770 times heavier than air. Hence, comparing equal volumes, a cubic foot of water in losing one degree of temperature would raise $770 \times 4{\cdot}2 = 3234$ cubic feet of air one degree.

'The vast influence which the ocean must exert as a moderator of climate here suggests itself. The heat of summer is stored up in the ocean, and slowly given out during the winter. This is one cause of the absence of extremes in an island climate.'[1]

Railway foot-warmers are filled with hot water, and the high specific heat of water enables it to warm the surrounding air for some time. This is the value of water in a heating apparatus.

It has been assumed that it requires the same amount of heat to raise a unit of mass of a substance through one degree, whatever the temperature may be. This is approximately true, and may be accepted as Boyle's law and Charles' law have been accepted.

45. Solidification.

It requires heat to change a solid body into the liquid state. Some substances, as ice, cast iron, bismuth, contract in liquefaction; others, as lead, gold, silver, expand in liquefaction.

The passage of a liquid to the solid state is termed solidifi-

[1] Tyndall, *Heat as a Mode of Motion.*

cation, and we might infer from the latent heat of fusion that in the process heat would become sensible, and affect thermometers.

Dissolve sodium sulphate in water at 30° C., dissolving as much as possible. Pour the liquid into 2 flasks, cover the mouths and allow them to cool without disturbing them. Take one flask and shake it; the solution solidifies. Place another in a dish containing methylated spirits, and in the same vessel place one bulb of a differential thermometer. Shake the flask, and as it freezes note the change in the thermometer.

Liquids in solidifying give out sensible heat. They cool down to the freezing-point; from the time freezing begins until it is completed the temperature is stationary. The amount of heat given up in solidification equals the latent heat of fusion; in the case of water it is 80. This is the reason why, when water is cooled down to 0° C. it does not at once freeze. Every lb. must lose 80 thermal units before solidification takes place; the water is a storehouse of heat.

1 cubic foot of water weighs $\frac{1000}{16}$ lbs.

1 " " " in freezing gives up $\frac{1000}{16} \times \frac{80}{1} = 5000$

units of heat, i.e. sufficient heat to raise 50 lbs. of water from freezing-point to boiling-point, or sufficient to raise 1 cubic foot of water to 80° C. This heat acts on the surrounding air and objects, and retards freezing. When the thaw comes it is not sufficient for the temperature to rise above freezing-point; sufficient heat must be given to the ice and snow (80 units for every lb.) Thus the thaw is gradual.

The density of water is greater than that of ice. 11 cub. ins. of water at 0° C. form 12 cub. ins. of ice at 0° C. The force exerted by water in freezing is very great; rocks are split in winter, and water-pipes burst at the time of frost, not of thaw.

46. Regelation.

Water in freezing expands. Suppose a cubic foot of water enclosed in a strong iron case; the water in freezing would exert

great force, and the iron must expand before the water can freeze at 0° C.

If the pressure were such that the covering remained rigid, it was argued that the water could not freeze at 0°. Experiment has verified this. By great pressure the freezing-point is lowered; a pressure of 135 atmospheres (15×135 lbs. on the square inch) lowers the melting-point 1°. This pressure is so enormous that no ordinary pressure affects the temperature of freezing (see Freezing-Point). A cubic foot of ice, if powerfully compressed, should melt. This also has been verified by experiment.

An interesting experiment results from this. A large block of ice rests at its ends on two supports; a piece of copper wire is placed round it and a heavy weight is attached to the wire. In half an hour the wire cuts its way through the ice, but the ice freezes again as the wire passes. The pressure due to the weight acts upon the small surface covered by the wire, and gives a great pressure per square inch. This pressure is sufficient to melt the ice. The water escapes round the wire, and the pressure being removed it again freezes.

Recent experiments show that if the block be in an ice-house, where the temperature is below 0° C., the wire is unable to cut its way through; the surrounding air must be above 0° C.

A number of pieces of ice floating in a pond or river often freeze together. They strike against each other, and the force is sufficient to melt the ice at the part where they meet; as they rebound the pressure is lowered and the remaining water freezes.

Pieces of ice can be pressed together and frozen into one piece in warm water.

Float a number of pieces of ice in a basin; observe how some pieces freeze together.

The term ***regelation*** is given to the above phenomenon.

Lead in freezing (passing into the solid state) contracts. By the above, if melted lead be compressed, its freezing-point ought to rise.

47. FREEZING MIXTURES are mixtures of bodies one of which at least passes from the solid to the liquid state. This requires heat. This heat is taken from the mixture and the temperature falls.

Take pounded ice or snow, place it in a vessel, stir into it half its weight of rough salt. Place water in a test tube and dip this into the mixture; the water freezes.

This is the principle of refrigerating or ice machines. The vessel containing the freezing mixture is protected on the outside by some non-conducting body, such as felt.

Other freezing mixtures :—

Sulphate of sodium	3 parts	Temperature is lowered from 10° to −18° C.
Dilute nitric acid	2 parts	
Phosphate of sodium	6 parts	Temperature is lowered from 10° to −29° C.
Dilute nitric acid	5 parts	
Crystallised calcium chloride	10 parts	from 10° to −50° C.
Snow	7 parts	

LATENT HEATS OF FUSION.

Water . . .	80·2	Sulphur . . .	9·4
Silver . . .	21·1	Lead . . .	5·4
Bismuth . .	12·6	Mercury . .	2·8

EXAMPLES. XXI.

1. On freezing water in a glass tube the tube sometimes breaks. Why is this? An iceberg floats with 1,000,000 tons of ice above the water line; about how many tons are below the water line?

2. Explain why water pipes burst in cold weather.

3. Ice melts at 32° F. and wax at 140° F. A mass of ice at 31° and a mass of wax at 139° are separately compressed by suitable means. Could either of them by a sufficient increase of the pressure be melted? Give reasons for your answer.

4. The images on gold and silver coins are stamped; good castings cannot be taken. Why? Could you obtain a sharp casting of ice or of bismuth?

5. 1 lb. of water and 1 lb. of salt, both at ordinary temperatures, are mixed. Will the temperature of the mixture change? Why?

6. What becomes of the heat that is used in melting ice? Is it lost?

CHAPTER VI.

CHANGE OF STATE FROM LIQUID TO GAS—VAPOURISATION—VAPOUR PRESSURE—CONDENSATION.

48. VAPOUR PRESSURE.

WHEN any liquid is heated its temperature rises and part of the liquid passes into the gaseous condition. If the heat be continued the liquid boils, and ultimately the whole evaporates. Boiling is not essential to evaporation ; the water placed in a saucer evaporates at ordinary tempertures ; the same thing takes place with the water of the sea.

When a liquid passes into a gaseous condition quietly, without boiling, the process is called *evaporation*. The change when accompanied with boiling is called *ebullition*.

FIG. 26.

EVAPORATION IN A VACUUM.—Fill three barometer tubes 33″ long with mercury, and invert them over mercury, supporting each by a clamp. The mercury stands at the same height in each. With a pipette force a few drops of water up one, B, and a few drops of ether up a third, C. The mercury sinks slightly in the tube containing the water, and to a greater degree in the ether tube. No liquid is seen in either tube ; it has all evaporated. The water vapour and the ether vapour must exert a definite pressure of so many inches of mercury. Continue to force water and ether up the tubes ; the mercury continues to sink ; ultimately it remains stationary, and the result of forcing up more liquid is that a layer of the liquid forms on the top of the mercury.

Warm with the hand the tubes containing the ether and

water ; the mercury is further depressed. Cool them with cold water ; the mercury rises, showing that the pressure is not so great.

Vapours have, then, a *maximum pressure* for any given temperature ; and this maximum pressure is exerted when the vapour is in contact with its own liquid.

EXAMPLE.

The mercury in tube A was 772 (fig. 26) millimetres high. In tube B, after adding water until a layer formed, the mercury was 760 millimetres above the level of the vessel.

In tube C, after adding ether until a layer formed, the mercury was 422 millimetres high.

The thermometer was at 14° C.

∴ the maximum pressure of water vapour at 14° is 772 – 760 millimetres = 12 millimetres of mercury.

∴ the maximum pressure of ether vapour at 14° C. is (772 – 422) millimetres = 350 millimetres of mercury.

The maximum pressure of a vapour depends upon the temperature and upon the kind of liquid used.

The maximum pressure of water vapour has been carefully determined at different temperatures.

Temperature C.	Pressure in Millimetres	Temperature C.	Pressure in Millimetres
–32°	0·320	15°	12·699
–20	0·927	18	15·357
–10	2·093	20	17·391
0	4·600	50	91·981
4	6·097	70	233·093
10	9·165	90	525·450
12	10·457	100	760·000

49. SATURATED AND UNSATURATED VAPOUR.

Remove the tube containing the ether into a deep mercury trough, depress it and raise it slowly ; measure the height of the mercury in each case ; as long as any liquid ether remains, and there is a space for the vapour, the height of the mercury remains constant. Depressing the tube simply causes more vapour to liquefy, and raising it causes more liquid to evaporate.

When the vapour is exerting its maximum pressure the space is said to be saturated; this is the case when the liquid and its vapour are in contact. A saturated vapour does not obey Boyle's law.

Repeat this last experiment, using a tube into which only one drop of ether has been introducea, so that all of it evaporates; no liquid is seen: the space is unsaturated.

Raise and depress as before; the height changes, and by measuring it will be found that an unsaturated vapour obeys Boyle's law, viz.

volume × pressure = constant, if temperatures be constant; and also Charles' law.

A saturated vapour obviously does not obey these laws; increased pressure liquefies part of the vapour.

50. MIXTURE OF GAS AND VAPOUR—BOILING-POINT.

FIG. 27.

Experiments have shown that the maximum pressure of a vapour is the same when mixed with any gas (say, air) as it is in a vacuum. The vapour of the liquid acts as if the gas were not present, save that evaporation takes place more slowly.

The temperature at which a liquid boils is called its ooiling-point. The boiling-point of a liquid depends upon the pressure, not upon the temperature.

Take a round-bottomed flask, fill it one quarter full with water, and boil it briskly for five minutes; when it is boiling insert a good india-rubber cork, and at the same moment remove the lamp. Invert the flask and let it cool. When the

boiling has ceased, pour cold water over it (fig. 27); the water begins to boil. The temperature is below the ordinary boiling-point. As it boils, pour *hot* water over the vessel, the boiling ceases; when it cools down again, repeat the experiment.

In cooling the water vapour condenses in the flask, the heat escapes through the glass. By pouring cold water upon the flask more vapour is suddenly condensed; the pressure is lowered below the pressure necessary to cause boiling.

The experiment can be performed in another form by causing water, ether, etc., to boil under the receiver of an air pump by exhausting, and thus reducing, the pressure.

Boil water in a flask A, and let it cool down to about 60° C. Boil briskly the water in C; close the clamp B upon thick-walled india-rubber tubing. Remove the burner, and at the same moment

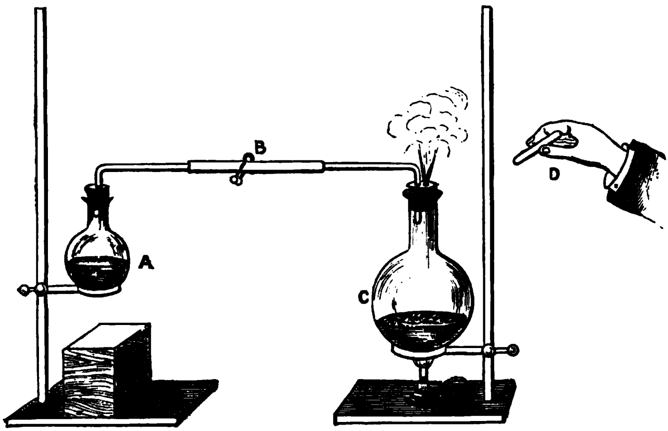


FIG. 28.

insert the glass stopper D. When C cools and the vapour in it condenses, connect the flask A. Open the clamp. The lowering of the pressure causes the water in A to begin to boil (fig. 28).

Water or any liquid boils when the maximum pressure of its vapour equals the pressure of the atmosphere.

BOILING-POINTS UNDER THE PRESSURE OF AN ATMOSPHERE.

Sulphurous acid .	−10°	Turpentine . .	160°
Ether . . .	37	Mercury . .	358
Alcohol . .	78	Sulphur . .	447
Water . . .	100	Zinc . . .	1040

Arrange apparatus as in fig. 29.

The bent tube A is filled with mercury up to ⅛″ of the open end; the remainder is filled up with water. By stopping the open

FIG. 29.

end and inverting, the water is run round to the long limb. The long limb is surrounded by a wider tube B, through which steam passes from the vessel C.

The pressure of the aqueous vapour increases until at length the mercury is level in both limbs, showing that its pressure is equal to the pressure of the atmosphere. This occurs when the water in the long limb boils. Force mercury out of the open limb by inserting a thick wire; the mercury still stands level in both limbs.

Increased pressure raises the boiling-point.

To the open tube in fig. 8 attach a bent tube; let the long end dip under 9″ of water. Boil the water. The steam is now under increased pressure and the temperature rises; observe the temperature. Use is made of this principle in Papin's digester.

The cover of the metallic vessel M is fastened down by a screw. The lever *b* presses upon a rod *u*, whose base is a valve pressing upon a hole in the cover. As the pressure increases, it raises *u* and the steam escapes. The pressure is regulated at five to six atmospheres by the weight *p*. The water can thus be heated to 200° C., and can be used for extracting gelatine from bones, or in a modified form it can be used on high mountains for cooking purposes.

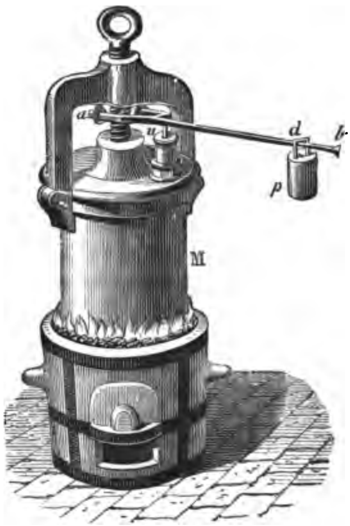


FIG. 30.

As we ascend the pressure of the atmosphere decreases; therefore the boiling-point is lowered. On high mountains water in an open vessel boils at a temperature insufficient to cook eggs.

By noting the temperature of steam from boiling water the height above the sea level can be calculated; a difference of 1° C. indicates roughly a difference of 1080 feet.

51. EBULLITION.

As water is heated vapour rises from the surface; small bubbles of air dissolved in the water are expelled. The water at the bottom is further heated; a circulation ensues: the heated water rises up the centre, the colder flowing down the sides. The water at the bottom is heated to the boiling-point. Bubbles of steam form and rise; these condense with a sharp sound before reaching the top. If these sounds be frequent simmering

ensues. When the temperature of the liquid above is too high to condense the bubbles, they escape at the top; the whole of the liquid rises to its boiling-point, and ebullition takes place. As has been seen in many cases, the temperature rises up to boiling-point and the thermometer then remains stationary.

LAWS OF EBULLITION.

(1) Every liquid has a definite boiling-point for a definite pressure; by decreasing or increasing the pressure the boiling-point is lowered or raised.

(2) A liquid boils when the maximum pressure of its vapour is equal to the pressure of the atmosphere.

(3) The temperature rises up to the boiling-point; it then becomes stationary until the whole of the liquid has evaporated.

EXAMPLES. XXII.

1. A flask containing water is heated. When the water boils the flask is carefully closed with a cork and removed from the flame. Explain why, when the flask is dipped into cold water, the water inside again begins to boil.

2. Explain why, in order to cook food by boiling at the top of a high mountain, you must employ a different method from that used at the sea level.

3. What is meant by the 'boiling-point' of a liquid? How is it affected by change of pressure?

4. Explain what happens when water is placed in the receiver of an air pump where the pressure is not more than 3 millimetres of mercury.

52. LATENT HEAT OF EVAPORATION.

As in fusion the heat given to the liquid as it boils is said to become LATENT; it ceases to affect the thermometer. The heat, we may assume, is engaged in tearing the particles of the liquid apart, so that they can appear as vapour.

The number of units of heat required to change one unit of mass of a liquid at its boiling-point into vapour at the same temperature, is called the LATENT HEAT OF EVAPORATION *of the liquid.*

To Find the Latent Heat of Steam.

A, a 16-ounce flask. B, a wide tube to prevent condensed water passing into A. C, an 8-ounce flask three parts full of water. Weigh A empty and three parts full of water; difference = weight of water. Place it on a pad of felt and surround it with felt. Protect A from the heat of the burner by a sheet of tin.

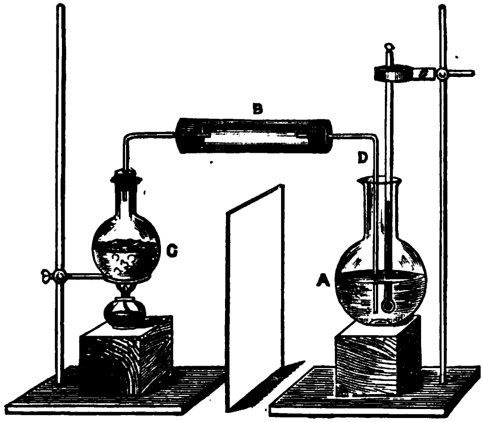


Fig. 31.

Boil the water in C. When the steam is issuing from the end of D, note the temperature of A, and then dip D into A. The steam condensing heats the water in A. Test with the thermometer; in about four or five minutes remove D and note the final temperature; weigh A and find the weight of steam condensed (fig. 31).

Example.

Flask A = 70·8 grams.
Flask A + water = 370·8 grams. Temperature = 13° C.
Flask + water + condensed steam = 391·1 grams. Final temp. = 52° C.

To heat 300 grams (52 – 13)°, i.e. 39 degrees, requires 300 × 39 = 11700 units of heat.

This is obtained from 20·3 grams of steam condensing and cooling from 100° to 52°.

20·3 grams cooling 48° give up (48 × 20·3) units of heat = 974·4 units of heat.

11700 – 974·4 = 10725·6.

10725·6 units must be given up by 20·3 grams of steam, condensing from steam at 100° to water at 100°;

$$\therefore \text{ 1 gram of steam gives up } \frac{10725{\cdot}6}{20{\cdot}3} = 528{\cdot}3 \text{ units of heat.}$$

The latent heat of evaporation = 528·3.
In accurate experiments it is 536.

The latent heat of evaporation of alcohol is 208, of ether 90.

53. Freezing by Evaporation.

The amount of heat required in evaporation is great. If evaporation take place this heat must come from somewhere; it may come from a flame, or it may come from neighbouring bodies, and thus lower their temperature, even to freezing-point.

(1) Sprinkle ether on the mercury thermometer and on the air thermometer, also on the hand. Explain why the thermometers indicate lower temperatures and the hand feels cold. Use water in the same way.

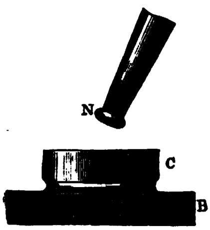


Fig. 32.

(2) Hammer a thin piece of copper into a shallow capsule (C). Float it on a little water poured on a block of wood (B), and pour carbon disulphide into the capsule; with a bellows (N) blow across the carbon disulphide; it evaporates, abstracts the heat from the water; the water freezes to the wood. Perform this in a cupboard or in the open air.

(3) If the pressure can be reduced with sufficient rapidity evaporation will take place. The air pump may be used for the purpose. It is necessary to remove the vapour as soon as formed, in order to induce fresh evaporation. For this purpose strong sulphuric acid is placed in the receiver to absorb the vapour.

(4) Wollaston's cryophorus is a bent glass tube with a bulb at each end containing water and water vapour; the water having been boiled, and the tube sealed while boiling to expel all air.

Place all the water in one bulb, A. Insert the other bulb in ice and salt: the water vapour condenses; evaporation takes

place rapidly from the water in A; heat is taken from it, its temperature falls, and it ultimately freezes.

It will be a useful exercise to notice the effect of heat upon 1 lb. of ice at 0° F.

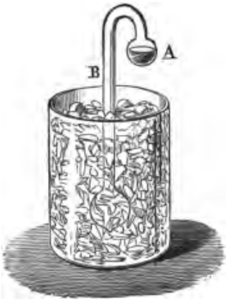


FIG. 33.

The S.H. of ice is about ·5. The latent heat of ice is 144 when the thermal unit is defined on the F. scale. The specific heat of water is 1 a t39·1° F., being slightly less below and more above that temperature; 182 units of heat, not 180, are needed to raise the temperature of water from 32° F. to 212° F. The latent heat of steam is 965. The specific heat of steam is ·485; that is, one unit of heat raises the temperature of 1 lb. of steam 2·08° F. The volume of steam at 212° will be about 1700 times the volume of water, and its volume will further increase according to Charles' law.

∴ the units of heat needed to change 1 lb. of ice at 0° F. to steam at 212° F. $= (\cdot 5 \times 32) + 144 + 182 + 965 = 1307$ thermal units.

If the volume of water at 39·1 be called 1, the volume of ice at 32° is 1·0908, the volume of water at 32° is 1·000127, and the volume of water at 212° is 1·04315.[1]

0° F. = −17·7° C. The number of units of heat required to change ice at −17·7° C. into water at 100° will be (the student can write out the account fully)

$$(17\cdot 7 \times \cdot 5) + 80 + 101 + 537 = 726\cdot 8 \text{ units} = \text{nearly } \tfrac{5}{9}(1307).$$

54. CONDENSATION—DISTILLATION.

When a vapour passes into the liquid form the process is called condensation. As was seen in § 52, the vapour in condensing gives up heat that affects thermometers. The heat given up in condensation equals the latent heat of evaporation.

DISTILLATION is an illustration of evaporation and condensation; the liquid in the vessel is heated, it passes into vapour, the vapour is condensed by cold.

LIEBIG'S CONDENSER.—The water is heated in the retort A; the vapour passes into the tube *g*; *g* is surrounded by another tube *j*, through

[1] Adapted from Maxwell's *Heat*.

which passes a stream of cold water fed from the tap; the water enters the lower end of the tube *g* by a tube B and escapes by the tube *t*. The vapour is condensed in *g* and pure water collects in the receiver C. In condensation heat is liberated; this heat raises the temperature of the cold water in *j* (fig. 34).

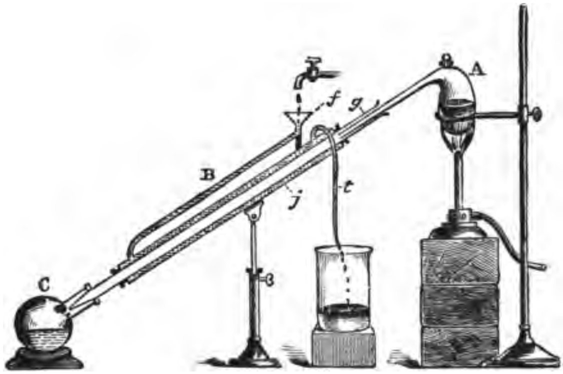


FIG. 34.

Water containing impurities can be purified by this means; the water evaporates freed from its impurities. Fit up such an apparatus; place in the retort a mixture of salt and water, distil it, and notice that the distilled water is free from salt.

A vapour (for example, aqueous vapour) is condensed (*a*) by lowering the temperature, (*b*) by increasing the pressure. By using one or both of these methods the so-called gases have been liquefied. The gases carbon dioxide and sulphur dioxide are found at ordinary temperatures to show a marked deviation from Boyle's law. These gases are easily liquefied; they behave like vapours that are nearly saturated (§ 49). A gas is the vapour of a substance, its temperature being much higher than the boiling-point of its liquid. The 'permanent' gases, oxygen, hydrogen, etc., are vapours of liquids whose boiling-points are greatly below the ordinary temperatures; they have all been liquefied by pressure when the temperature has been lowered sufficiently.

EXAMPLES. XXIII.

1. Describe a method of determining the latent heat of steam.

2. A beaker containing water is heated by a Bunsen flame. A Centigrade thermometer, placed in the water, rises to 100°, but no higher, and the water begins to boil. What is the reason that the thermometer does

not rise higher than 100°? and what becomes of the heat which is thus apparently lost?

3. I once went into a room, the doors and windows of which had been kept shut for some time, and the temperature of which was 80° F. I took some water (also at 80°) and sprinkled it over the floor, and the temperature at once fell several degrees. How do you explain this?

4. What is meant by the 'latent heat of vapourisation'? If the latent heat of vapourisation be 966 when one degree Fahrenheit is the unit of temperature, what will it be when one degree Centigrade is the unit? Would your result be different if the unit of mass had been changed?

5. If you dip your hand into lukewarm water and then expose it to the air, the hand feels cold. If you make the same experiment with ether the hand feels much colder on exposure. Explain these facts.

6. Describe the cryophorus. Is water essential? Could alcohol be used?

7. How would you obtain pure water from sea water? What becomes of the heat in distillation that is given up during condensation?

8. Describe the changes which take place when heat is applied to one pound of ice at 0° C., until it is converted into vapour. Account for the difference in the quantity of heat required according as the ice is in an open or a closed vessel.

9. Describe 'distillation.' How could a liquid be distilled at a temperature (*a*) below its ordinary boiling-point and (*b*) above its ordinary boiling-point?

10. Explain the difference between a gas and a vapour.

CHAPTER VII.

HYGROMETRY.

55. Aqueous Vapour is always Present in the Air

(1) Place pieces of calcium chloride or caustic potash in saucers in a room; the salts melt in the water they abstract from the air.

(2) Dry the outside of a flask thoroughly; pour into it cold spring water: vapour is condensed and deposited on the outside of the cold flask.

(3) Breathe against a cold surface. Condensation takes place.

The aqueous vapour present in the air is condensed when the temperature is sufficiently lowered. This temperature is evidently the temperature at which the air is saturated with aqueous vapour.

The temperature at which the air is saturated with aqueous vapour—that is, the temperature at which vapour is condensed—is called the 'DEW POINT.'

Aqueous vapour is water in the gaseous condition; in steam the gas has condensed into minute particles of liquid water.

Our common expressions 'dry air,' 'moist air,' simply express the effect of the air on ourselves and surrounding objects. They give no information as to the exact amount of moisture in the air.

In the 'dry air' of tropical countries there is much more actual moisture in a cubic foot of air than in England.

The air is 'dry' when its temperature is many degrees above the point at which condensation will take place. There is generally more actual moisture in the air in summer than in

winter. In summer the temperature is far above the dew point. In winter the temperature may be only slightly above the dew point; this causes the feeling of dampness.

56. Hygroscopes.

For roughly showing the dampness or dryness of the air hygroscopes are popularly used.

(1) Cut a piece of gold-beater's skin into the figure of a mermaid, and place it on the hand. The dampness of the hand causes it to assume fantastic shapes.

(2) Twisted catgut absorbs moisture, twists up and shortens when the air is damp, and untwists when the air is dry.

Fig. 35.

In the illustration the twisting of the catgut attached to *a* raises the monk's cowl, and he appears hooded when rain is imminent. The hood falls in dry weather.

(3) A long human hair, cleaned by boiling in a dilute solution of carbonate of soda and then dried, if stretched by a slight weight contracts when the air is damp. By twisting it round a small pulley an index can be moved.

57. Hygrometers.

Hygrometry deals with the amount of aqueous vapour present in the air. The instruments used in the science are called Hygrometers.

The ratio of the weight of aqueous vapour actually present in the air to the greatest weight the air could contain at that temperature is called the degree of saturation, or the humidity of the air, or the hygrometric state of the air.

To Find the Weight of Aqueous Vapour in Air.—(1) Weigh calcium chloride in a small basin; cover the basin with a bell-jar; suppose the bell-jar contains one cubic foot of air, weigh the basin after some time. The increase in weight will be the amount of aqueous vapour in 1 cubic foot of air.

(2) Place calcium chloride, or pumice-stone dipped in strong sulphuric acid, in tubes (both substances absorb aqueous vapour). Weigh the tubes; then pass, say, 20 gallons of air through them. The increase in weight equals the amount of aqueous vapour in 20 gallons. This forms a chemical hygrometer.

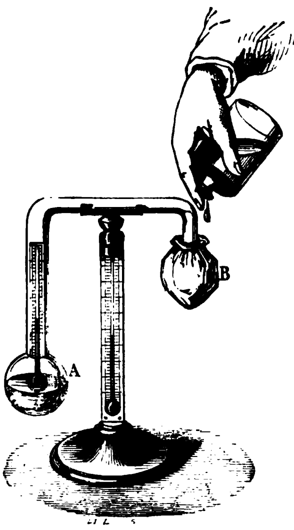


Fig. 36.

To determine accurately the hygrometric state of the air it is often necessary to know the dew point. Condensation hygrometers may be used for this purpose.

If in the experiment in § 53 the bulb of the cryophorus be observed, a film of dew is formed upon it at a certain temperature. If we could determine this temperature the cryophorus could be used as a condensation hygrometer.

Daniels' Hygrometer.

Ether is placed in the cryophorus, instead of water; a delicate thermometer is fixed in one bulb A (fig. 36); the ether is

heated and the apparatus sealed. B is covered with cambric; ether is poured on it; it evaporates and cools the bulb B. The ether in A evaporates, is condensed in B, and the temperature in A falls. When dew appears on a part of A that is bright, the temperature is taken; this is too low. On ceasing to pour ether on B the temperature at A rises, and the film of dew disappears; this temperature is too high. The mean is the dew point. The thermometer on the stem gives the ordinary temperature of the air.

Regnault's Hygrometer.

Clamp a test tube (A); fit into it a cork with 3 holes; in the centre hole insert a thermometer, in another fit a tube dipping to the bottom of the test tube; connect this by india-rubber tubing to a pair of bellows (fig. 37); in the third hole fix a tube open to the air. Place about 2 inches of ether in the test tube; place the cork so that the thermometer and the first tube dip below the ether; dry the outside carefully.

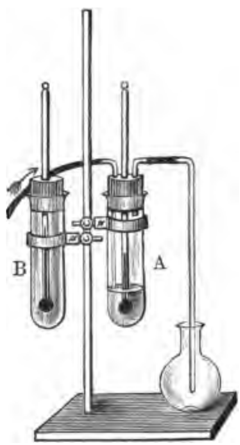


Fig. 37.

Blow gently with the bellows, and place the eye so that light is reflected from the tube near the ether; in a short time the outside of the tube is bedimmed. Note the thermometer and cease blowing; watch the dimness disappear and again note thermometer.

The mean = dew point.

In more expensive apparatus the bottom of the tube consists of thin polished silver. A thermometer placed in another empty test tube (B) gives the temperature of the air; by observing and comparing the surfaces of both test tubes the formation of dew is more easily seen on the tube containing the ether.

58. The Wet and Dry Bulb Hygrometer.

When the atmosphere is dry evaporation takes place more rapidly than when it is nearly saturated. The rate of evapora-

tion and its effect on a thermometer is used in determining the dew point.

Two thermometers are fixed side by side. Round the bulb of one a little lamp-wick is fastened, the end of which dips into water. The water rises in the wick and evaporates on the bulb; the temperature is lowered. The further removed the air is from saturation the lower the temperature of the wet bulb will be below that of the dry bulb. It is found that the dew point, at ordinary temperatures, can be found from the following formula:

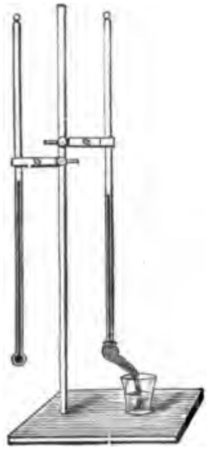


FIG. 38.

$$F = f - \frac{d}{87} \times \frac{h}{30}.$$

d = difference in the indication of wet and dry bulb in degrees Fahrenheit,

h = height of barometer in inches,

f = maximum pressure of vapour at the temperature of the wet bulb,

F = maximum pressure of aqueous vapour at the temperature of the air (from which the dew point can be found from the tables).

This looks complex, but it has the advantage over the condensation hygrometer that f, d, and h can be noted accurately, whereas there is some difficulty in determining by the other hygrometers the exact temperature at which dew is deposited. The reason for the formula is not easily understood; its results agree with the best results of other hygrometers, and that being the case we must be content to accept it.

59. Worked Examples.

[One cubic metre of dry air at 0° C. and at a pressure of 760 millimetres of mercury weighs 1293 grams. By § 33 the weight of 1 cubic metre at t° C. and P millimetres pressure will be $\frac{1293 \times P \times 273}{760 \times (273 + t)}$. The density of aqueous vapour is $\frac{5}{8}$ that of dry air under the same conditions of temperature and pressure.

1. Three cubic metres of moist air were drawn through a chemical hygrometer, and 34·68 grams of water were deposited in it, the temperature of the room being 18° C. Find the hygrometric state of the air.

From the table on p. 55, the maximum pressure of aqueous vapour at 18° C. is 15·35 millimetres.

The weight of 3 metres of saturated aqueous vapour at a pressure of 15·35 millimetres and a temperature 18° C. is $\frac{5 \times 1293 \times 15·35 \times 273}{8 \times 760 \times 291} \times 3$ grams $= 45·94$ grams.

The hygrometric state is the ratio of the quantity of aqueous vapour actually present to the quantity which would be present if the air were saturated;

$$\therefore \text{the hygrometric state} = \frac{34·68}{45·94} = ·75.$$

2. The dew point is at 12° C. and the temperature of the air in a room is 17° C.; find the hygrometric state of the air, the maximum pressure of aqueous vapour at these temperatures being 10·46 and 14·42 millimetres respectively.

The actual amount of vapour present is the amount that would fully saturate the air at 12° C.; that is, 1 cubic metre weighs $\frac{5 \times 1293 \times 10·46 \times 273}{8 \times 760 \times 285}$ grams (a); at 17° C. 1 cubic metre could contain

$$\frac{5 \times 1293 \times 14·42 \times 273}{8 \times 760 \times 290} \text{ grams } (b);$$

$$\therefore \text{hygrometric state} = \frac{a}{b} = \frac{10·46 \times 290}{14·42 \times 285} = ·74.$$

3. In the above example find the weight of 1 cubic metre of the air, the barometer being at 750.

It is a mixture of 1 cubic metre of dry air at temperature 17° C. under a pressure of (750 − 10·46) millimetres and 1 cubic metre of aqueous vapour at a temperature of 17° C. and a pressure of 10·46 millimetres.

$$\text{Weight of 1 cubic metre of dry air} = \frac{1293 \times 739·54 \times 273}{760 \times 290} \text{ grams}$$

$$\text{,, ,, ,, vapour} = \frac{1293 \times 10·46 \times 273 \times 5}{760 \times 290 \times 8} \text{ grams.}$$

The answer is the sum of these quantities.]

Examples. XXIV.

1. Describe any popular hygroscope.

2. A person wearing spectacles finds that on entering a hothouse his spectacles are bedimmed. Explain this.

3. When is space said to be saturated with vapour, and what is the effect (*a*) of a rise, (*b*) of a sudden fall in temperature in a space which is so saturated?

4. What is saturated vapour? If a cubic foot of atmospheric air be compressed into half a cubic foot without any change of temperature, what change of pressure occurs? If a cubic foot of saturated vapour be similarly compressed into half a cubic foot, what change of pressure occurs? Give reasons for your answers.

5. Describe any 'dew-point hygrometer,' and explain how, by its means, the moisture of the air may be determined.

6. How would you determine the hygrometric state of the air by means of Regnault's hygrometer?

7. Under what circumstances is dew formed? What is the dew point? How will the determination of the dew point give the pressure of the vapour of water in the atmosphere?

8. Explain what is meant by the dew point. How does the dew point show the amount of vapour in the atmosphere? Describe the mode of action of a dew-point hygrometer.

9. The temperature of a room is 20° C.; the dew point is 10° C. Find the hygrometric state of the air.

10. Find the weight of 10 cubic metres of the air in No. 9.

CHAPTER VIII.

CONVECTION AND CONDUCTION.

60. Convection.

In ebullition it has already been observed, how heat is carried from one part of the liquid to another, by the particles of the liquid being heated and carrying the heat with them as they move. Transference of heat by particles is called convection.

Pour slightly warm water into a beaker as wide as possible. Place pieces of ice in a test tube, and dip the test tube into the water. By throwing light pieces of bran, etc., into the water, convection currents can be seen moving in the direction of the arrows. Remove the test tube and apply a small flame at the lower part; again the currents circulate. Use both ice and flame; the currents move at a quicker rate (fig. 39).

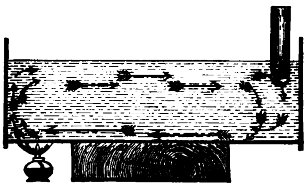


Fig. 39.

Water when heated expands; when cooled to 4° C. it contracts. The water near the flame expands; bulk for bulk therefore it is lighter than the surrounding water. This forces it upwards and a current is formed. Near the ice the water contracts and becomes denser than the water below it; it therefore sinks and a current is formed.

Imagine the beaker to represent the ocean, the test tube the icebergs and ice of the polar seas; the reason for an upper current from the equator to the poles is apparent. Water

conducts heat badly; the heat of the sun therefore has less to do with the currents than the polar cold.

61. VENTILATION.

Hold smouldering paper near a flame; the direction of the currents of air is seen.

A flame can only burn in the air if the air be continually renewed. Float a candle on a cork; place a bell-jar with open top over it: the candle is soon extinguished. Relight and place a piece of cardboard cut like a T square down the mouth; the candle burns. Hold smouldering paper near, and notice the direction of the currents—down one side of the cardboard, up the other.

Hold a tube over a candle; observe the increased brightness of the flame; show with smouldering paper that there is an increased draught up the tube. The candle represents a fire, the tube the chimney. Heat the tube at its upper part; the draught is improved (fig. 40).

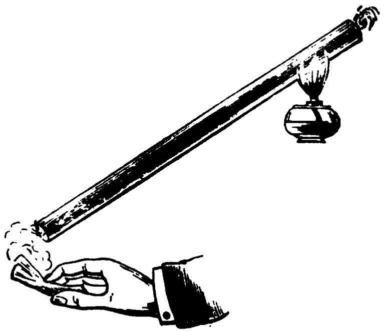


FIG. 40.

The heated air expands, becomes less dense than the surrounding air; the denser air sinks and forces the heated air upwards. The warmer the air in the tube, the greater force the colder air exerts; hence the improved effect in heating the tube.

The draught in chimney is due to the difference between the weight of the air outside and inside the chimney; the higher the chimney the greater this difference will be. Narrow chimneys are better than wide ones, as descending currents are prevented.

62. HEATING WITH HOT WATER.

A, an inverted bell-jar; B, an 8-ounce flask; tubes as in figure. Fill all with cold water; see that all bubbles of air are out

of B; place a few fine particles of cochineal or pulp (obtained by grinding paper in a mortar) in the water. Colour the water in A, applying heat (fig. 41).

The hot water rises up the twisted tube; cold water descends by the straight tube. The circulation can be easily observed.

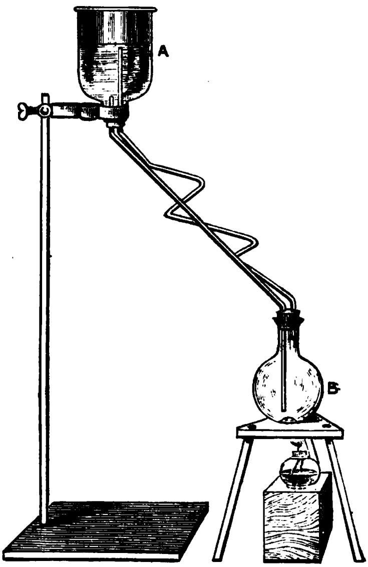


FIG. 41.

B represents the boiler of a heating apparatus; A, the supply cistern. A pipe runs from A to the *bottom* of the boiler; the pipe that supplies warm water rises from the *top* of the boiler. The pipe carrying the hot water must be so placed that there is a continual ascent of the water; it must not bend downwards. The hot water in the pipes cools slowly, and in cooling gives up its heat and warms rooms, etc.

63. CONDUCTION.

Place the end of a bar of metal (a poker) in the fire; heat travels along the bar, and soon parts cannot be touched with safety.

The transmission of heat in this manner, by flowing from particle to particle, is called CONDUCTION.

Place a copper and an iron rod, same diameter, end to end; heat the junction with a flame. *After some time* note the point farthest from the junction where an ordinary match can be ignited without friction. With particles of solid paraffin find the point where paraffin just melts.

	Copper	Iron
Match ignites at distance of	12 inches	6 inches

Copper conducts heat better than iron.

Place a silver spoon, an electro-plated spoon, and a leaden spoon in hot water; test after a few minutes the ends with the finger, also with thermometer, and arrange them in order as to their conducting power—their conductivity.

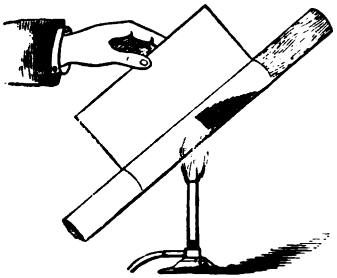


FIG. 42.

Fasten a cylinder of wood into a brass tube of the same outside diameter. Wrap a piece of white paper tightly round the junction and apply a flame.

The brass conducts the heat away so rapidly that the paper is left unscorched. Wood is a bad conductor and the heat therefore scorches the paper.

Place a fine piece of muslin on a sheet of lead; drop a live coal upon it.

Lead conducts the heat away, and the muslin is not burnt; on wood the muslin at once is scorched.

Fill an egg-shell with water; place it in the fire: the heat is rapidly conducted away by the water.

Make a cone by twisting foolscap paper, as is done by shopkeepers. Fill this with water, and boil the water by placing it on the fire.

The egg and paper are not burnt.

Place a few scraps of lead in a pill-box; heat gently at first. The lead melts in the box. Place a strip of the lid in the molten lead; it is charred.

64. To Compare the Conducting Powers of Solids.

Clamp the air thermometer. Place the cylinder of lead on the top. Heat the cylinder of copper in boiling water. Hold it a minute in the steam to drain; place it on the lead and wait *two minutes*. Notice the greatest depression in the scale. Remove the lead and use similar cylinders of bismuth, brass, cork,

wood, and another cylinder of copper, always using the copper cylinder as above.

By this means arrange the substances in the order of conductivity: (1) copper; (2) brass; (3) bismuth; (4) wood; (5) cork. Each cylinder is subjected to the same heat and each is the same length.


FIG. 43.

Take a coffee-tin. Punch a hole in the side; pour a little water into the tin, place on the lid, and boil. Take the bismuth and the copper cylinder; warm gently; smear one side with wax and allow it to harden; place both on the lid with the smeared face upwards: the wax on the bismuth melts first.

Compare this with the order above, and examine the table of specific heats.

The reason is that it takes less heat to raise the bismuth 1° of temp. than it does copper. Bismuth the sooner reaches the temperature at which wax melts. If *after some time* we try which is at the higher temperature with the thermometer, the copper will be the higher; it is the best conductor. You now understand why throughout this chapter the words *after some time* have been used.

65. CONDUCTIVITY.

In all experiments relating to conductivity the flow of heat must be steady.

The *relative* conductivity has been found as follows. It is merely an extension of the last experiment. Rods of metal of the same diameter are inserted into the sides of a trough and are covered with wax. The trough is filled with oil and heated. *When the flow of heat is steady* the distance on each bar on which the wax is melted is measured. The greater the distance the greater the conductivity of the metal. By observing the wax melted at the beginning of the experiment before the flow of heat is steady, the specific heats can be roughly compared

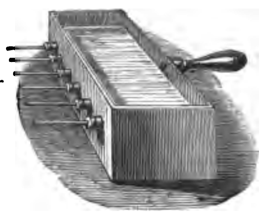


FIG. 44.

The numbers obtained are relative ; they have no absolute value. We cannot say what 80 means on this scale ; we do not know the unit. The numbers are like the words *very high*, *high*, *low*, applied to a building. Absolute numbers are like 200 feet, 170 feet, 20 feet.

Relative Conductivity of Metals.

Silver	100	Iron	12
Copper	74	Lead	8
Brass	24	Platinum	8
Tin	15	Bismuth	2

66. Absolute Conductivity.

[In order to define the *absolute* conductivity of metals, the following construction is imagined :—

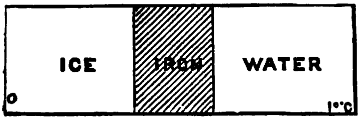


Fig. 45.

A cube of metal, 1 centimetre side, separates a vessel containing ice at 0° C. from a vessel containing water at 1° C. (fig. 45). The amount of ice melted in one second, when the *flow of heat is steady*, can be calculated.

Definition.—The thermal conductivity of a substance is measured by the number of units of heat which pass through a bar, the area of whose cross section is 1 sq. cm. and whose length is 1 cm., in 1 sec., when the temperatures of the ends differ by 1° C.

Units . . 1 cm. . 1 sec. . 1 gram

Write out the definition when the units are 1 kilogram, 1 mm., 1 sec.

Write out the definition when the units are 1 lb., 1 inch, 1 sec.

The amount of heat conducted will vary *directly* as the area, as the difference in the temperatures of the ends, as the time, and inversely as the length.

Example.

One side of a brass plate 1 centimetre thick and 1 square decimetre in area is kept in contact with boiling water, and the other side with melting

ice, and it is found that in 8 minutes 64·92 kilograms of ice are melted. Find the conductivity of brass in cm. gm. sec. units.[1]

Area = 100 cm. Length = 1 cm. Time = 480 secs. Mass of ice melted = 64920 grams. ∴ Number of thermal units = 64920 × 80. Difference in temperatures in degrees C. = 100.

Area in sq. cm.	Length in cm.	Difference in temp. of faces (C.)	Time in secs.	Units of heat
100	1	100	480	64920×80
∴ 1	1	1	1	$\dfrac{64920 \times 80}{100 \times 100 \times 480}$

$$\therefore \text{ thermal conductivity of brass} = \frac{64920 \times 80}{100 \times 100 \times 480} = 1{\cdot}082$$

when the units are *c—g—s*.

[1] *Examples in Heat*, by R. E. Day, Longmans.]

67. Conductivity of Liquids.

Pass the air thermometer through a bell jar, as in fig. 46. Fill the jar nearly to the top with water. Float a small dish on the top containing alcohol; ignite the alcohol.

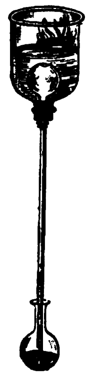


Fig. 46.

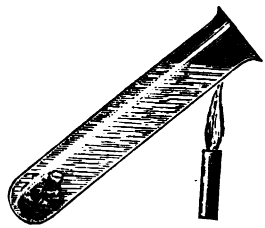


Fig. 47.

The index does not move, showing that water is a bad conductor.

Repeat the experiment, filling the jar with mercury; the index moves at once. Mercury is a good conductor and is an exception among liquids.

Wrap copper wire round ice until it will sink in water; place it in a test tube and cover it with water; heat the upper part with a small flame (fig. 47).

The water can be boiled at the upper part without melting the ice. In the experiment with the air thermometer use a beaker containing a freezing mixture instead of alcohol; the index rises. This is not *conduction* but *convection*. The water cools and becomes denser; thus it sinks.

The conductivity of liquids, except MERCURY, is very small compared with that of metals.

The conductivity of gases is smaller still than that of liquids; in both heat is conducted by convection or radiation.

68. ILLUSTRATIONS.

The feeling of warmth or cold in our bodies is due in the greater part to conductivity.

Iron is a good conductor, flannel a bad conductor. If we touch both at a temperature below that of the hand, the iron conducts rapidly the heat from the hand. The hand feels cold. In the case of the flannel little heat is conducted away. If above the temperature of the hand, iron rapidly gives up its heat; more is conducted to the part we touch; it feels warm. In flannel, again, little is given to the hand, and heat from other parts is not conducted to the place we touch (§ 1). In a Turkish bath the temperature is very high; while we can touch woollen materials, and use carpet slippers or rest on wooden boards, a piece of iron would burn us.

In Arctic expeditions all iron bodies are wrapped in flannel to prevent dangerous scalds by intense cold. Wood can be safely touched.

Ice is packed in flannel or felt in summer; being bad conductors they do not conduct the warmth to the ice. We dress in woollen fabrics in winter because they conduct very slowly the heat of our bodies to the external air. Water pipes are covered with straw in winter to prevent freezing. Hot lava has flowed over beds of ice protected by ashes without melting the ice. Travellers imbed themselves in snow to prevent freezing, snow being a bad conductor.

The brazier holds his tool with a wooden handle. The fur in the kettle, being a bad conductor, retards boiling.

69. Safety Lamp.

Lower a square of iron or brass gauze with close mesh upon a flame. The flame burns below the gauze (fig. 48). Put out the gas, and placing the gauze two inches above the pipe, turn the gas on. Light the gas above the gauze. It burns, but the gas below

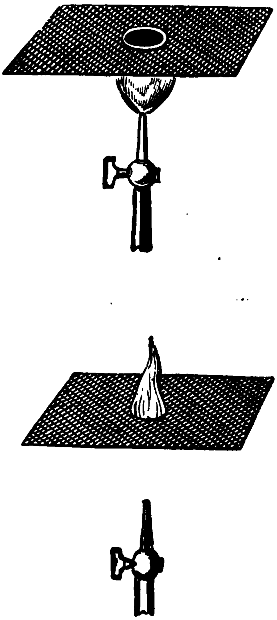


Fig. 48.

Fig. 49.

is not ignited. The gauze conducts away the heat so rapidly that the temperature of the part near the flame does not rise high enough to ignite the gas.

The safety lamp is surrounded by a gauze of close mesh. It is lighted before entering the mine. Even if surrounded by an explosive gas the heat is conducted away rapidly, and the

gauze is never heated sufficiently to ignite the gas; the flame goes out when the air becomes impure, and the flame is an indication of the danger the miner is subjected to. A strong wind or a sound wave caused by an exploding shot may force the flame *against* the mesh, heat it, or even force it through, and thus cause explosions. The Davy safety lamp (fig. 49) is, then, not absolutely safe, and serious attempts are being made to improve it.

EXAMPLES. XXV.

1. In the coldest or hottest weather you can handle wood without pain, but not metal. How is this?

2. How would you compare the conducting power of zinc and silver?

3. How would you show that (*a*) mercury is a good conductor and (*b*) water is a bad conductor? If mercury and water be both at the temperature of the room, the mercury feels colder to the touch than the water. Why?

4. Explain the construction of the safety lamp.

5. Two equal bars of copper and bismuth are coated with wax; one end of each is exposed to the same source of heat. When first examined the greater amount of wax is melted on the bismuth; after some time the greater amount is melted on the copper bar. Explain these facts.

6. When very short cylinders of lead and copper are placed with one end of each in contact with a hot body, it is found that the other end of the lead cylinder gets hot soonest, whereas with longer cylinders of the same metals the reverse appears to be the case. Explain the reason of this.

7. How many gram degrees of heat will be conducted in an hour through an iron bar two square centimetres in section and four centimetres long, its extremities being kept at the respective temperatures of 100° C. and 178° C., the mean conductivity of iron being ·12? (The units are a gram, a centimetre, a second, and a degree Centigrade.)

8. What is meant by the conductivity of a body for heat? Show how the conductivity of a bar of iron may be accurately determined. An iron boiler containing water at 100° C. is 3 centimetres thick, and keeps the room in which it is placed at a temperature of 30° C. If the conductivity of iron is 1·29 unit per hour, find how much heat is given off per hour from one square centimetre of the surface.

CHAPTER IX.

RADIANT HEAT—REFLECTION—ABSORPTION—RADIATION—TRANSMISSION.[1]

70. RADIANT HEAT.

WHEN heat is transmitted by *conduction*, particle after particle of the body is heated; in *convection* small particles are heated, and these move and carry heat with them.

Conduction and convection do not explain how the heat of the sun reaches the earth, nor how the heat of the fire warms the room. There is no medium between our atmosphere and the sun that can conduct heat or transmit it by convection. The heating of the room is not accompanied by currents of warm air spreading from the fire.

On mountains, the heat of the sun is frequently oppressive in one place, while a few yards away in the shade it is intensely cold. If the air *conducted* the heat of the sun, or was a means of *convection*, such a marked difference would not be felt. In the glare of summer sun a sunshade at once gives relief. A hand screen held between the face and the fire at once protects the face. The heat is transmitted without heating the air, and the heat is only felt when it is stopped by the earth, our bodies, or some object. Heat transmitted in this way is called radiant heat.

It is believed that radiant heat is propagated in waves, and for the time being is not sensible heat; these waves strike an object and heat it. Radiant heat can be tested experimentally to examine whether, like light, it is reflected and refracted.

[1] This chapter should be read after the chapter on Reflectiou of Light.

71. Reflection.

Blacken one bulb of the differential thermometer with lamp-black : the bulb becomes more sensitive ; it absorbs heat better than before. Draw a semicircle on the table 2½ feet radius, and graduate it as in fig. 50. At the centre place a sheet of tin M vertical. Place one of the tin tubes on the radius 40 ; heat the copper ball C, and place it at the end of this tube. Move the other tin tube, pointing one end to the centre, the blackened bulb of the thermometer T being in the other end, until the index moves ; find the position carefully ; the tube will be over 40° to the right of 0°. Experiment in different positions.

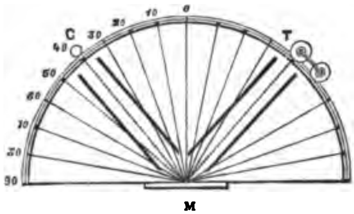


Fig. 50.

Position of Ball	Position of Thermometer
40	40
60	60
10	10

Heat is reflected according to these laws :—(1) The angle of incidence equals the angle of reflection. (2) The incident ray, the normal, and the reflected ray are in one plane.

Compare reflection of light and sound.

While the ball is at 30° and the thermometer at 30°, move the tin plate, and substitute cardboard blackened with lampblack ; the thermometer indicates that no heat is being reflected. Replace the tin plate ; the index at once moves.

When the ball is very hot, note the movement caused by the tin plate ; replace it by a plate of polished brass : the thermometer indicates that more heat is being reflected.

Polished brass is a good reflector.
Polished tinplate is a fairly good reflector.
Lampblack is a bad reflector.

By such experiments (the weakness of our arrangement is that the ball cools rapidly) and by using a source of heat that

remained constant, substances have been arranged according to their comparative powers of reflecting radiant heat.

Polished brass . .	100	Lead . . .	60
Silver	90	Glass . . .	10
Tin	80	Lampblack . .	0
Steel	60		

72. Reflection from Concave Mirrors.

By using concave mirrors it can be shown in a more striking form that radiant heat is reflected in the same way as

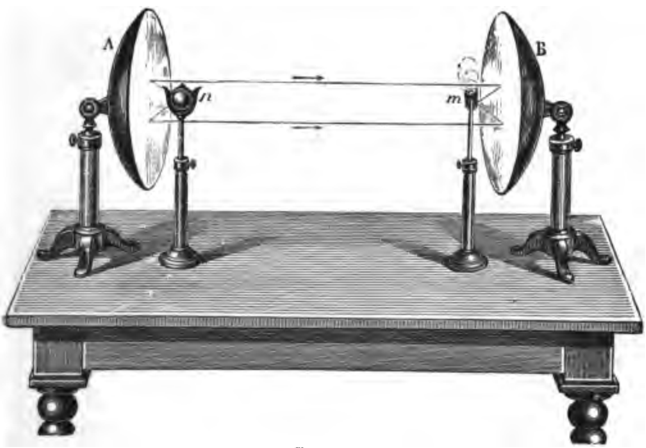


Fig. 51.

light. The mirrors are arranged and their foci determined (see 'Light'). At one focus, *n*, is placed the hot copper ball; a piece of phosphorus placed at the other, *m*, is at once ignited, or a small flask of water can be warmed.

Protect *m* by a screen from the direct rays from *n*. No change is made in the heating effect.

If one of these mirrors be directed to the sun, pieces of wood or paper are ignited at the focus. The derivation of the word *a hearth* is apparent.

Substitute a flask containing ice and salt for the copper ball; test the other focus with the thermometer: *apparently* cold is reflected. See § 78.

The rays of heat pass from the ball to its mirror; they are then reflected to the other mirror; from it they are reflected to the focus.

Leslie's arrangement was as follows :—

He used one reflector; his source of heat was a cube containing water kept at boiling-point; the conjugate focus is at F (fig. 52). (See 'Light.') He arranged a small plane reflector

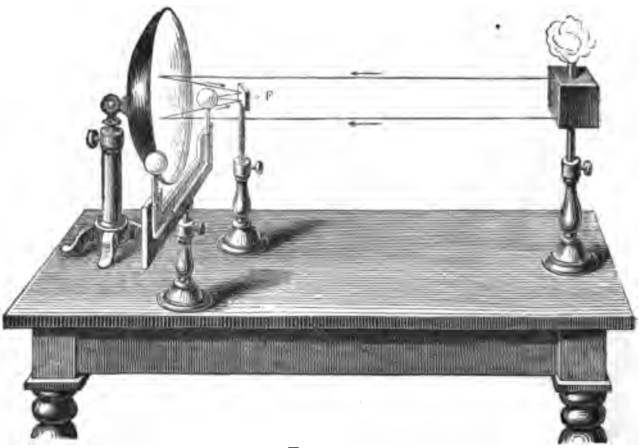


FIG. 52.

between the mirror and F, so as to focus the heat rays upon the thermometer. He then used different reflectors, and from the effect upon the thermometer constructed his table.

73. ABSORPTION AND REFLECTION.

If in fig. 52 the reflecting surface (the small square) were very thin, and were the side of a cube that formed the large part of an air thermometer, we could at the same time compare the absorbing power and the reflecting power of a body. In the actual experiments Leslie removed the reflecting body and

placed the differential thermometer at the focus, covering the bulb in turn with lampblack, gold leaf, tinfoil, etc., and constructed a table showing the relative absorbing powers of bodies.

Take two sheets of tin ; cover one side of one with lampblack ; place them each one foot from the hot copper ball, with two thermometers applied to the sides away from the heat. Test which absorbs most heat, or make a differential thermometer with a long connecting tube, so that a bulb is behind each plate. The back of the plate that has the blackened side turned to the ball is heated much more than the other.

Other illustrations of the absorbing power of bodies are numerous.

Water boils more quickly in a kettle covered with soot than in one new and polished. The soot absorbs heat better than polished metal.

Place the differential thermometer so that both bulbs are at the same distance from the hot copper ball ; the index informs us that the blackened bulb absorbs more heat than the clean bulb.

In winter the ice and snow beneath the ashes melt sooner than the ice that is uncovered ; the ashes are good absorbers.

THE BEST ABSORBERS (lampblack, ashes, rough surfaces) are the bodies that were found to be BAD REFLECTORS, while GOOD REFLECTORS (polished metals) are BAD ABSORBERS.

74. RADIATION.

Bodies not only reflect heat but radiate heat from their surfaces when they have been heated.

Comparative experiments are easily performed.

Fill four similar coffee tins with hot water, having previously painted one with lampblack, a second with isinglass, pasted tissue paper over a third, leaving the fourth bright. Place them on a piece of wood, and test them in five minutes.

Bright tin.	Isinglass.	Paper.	Lampblack.

The lampblack has radiated most heat, the polished tin least. By repeating this with different materials a comparative table can be constructed.

Treat the four sides of the Leslie cube in this way (cover one with lampblack, etc.), and hold the thermometer at equal distances from the surfaces.

Leslie used the apparatus in fig. 52, coating the cube with the substance and keeping the same reflector; from the effect on the thermometer he deduced the table of radiating or emissive powers.

Good radiators are good absorbers and bad reflectors.

Bad radiators are bad absorbers and good reflectors.

The absorbing and radiating power of a surface are equal.

75. DIATHERMANCY.

Some bodies—such as glass, air—transmit heat. The heat of the sun reaches us through the air, and the glass of the windows does not prevent it entering our rooms. Bodies differ in their power of allowing radiant heat to pass through them. Bodies that transmit radiant heat are called DIATHERMANOUS. Bodies that do not transmit radiant heat are called ATHERMANOUS.

Using either a sunbeam or a parallel beam from a lantern, allow it to fall upon a thermometer; interpose a glass cell filled with water and observe the temperature of the thermometer; when it is steady test the temperature of the water.

Repeat the experiment, using carbon disulphide.

Water transmits fewer heat-rays than carbon disulphide, but it absorbs more; therefore its temperature rises higher than the temperature of carbon disulphide.

In winter repeat the experiment, using a clear sheet of ice; ice refuses to transmit the rays, but it is rapidly melted.

Although water and ice are more transparent to light than carbon disulphide, they transmit less heat.

With a lens focus the rays after they pass through the carbon disulphide upon a piece of platinum, add iodine to the liquid until no light passes, and note that heat still passes and affects the platinum.

Heat may be transmitted without being accompanied by the phenomenon of light.

The amount of heat transmitted depends upon the source of heat; for instance, glass transmits heat fairly, when the source is at a high temperature (the sun, a hot fire), but transmits none when the source is at a low temperature (heated furniture, walls of greenhouses). Windows of a greenhouse allow many rays of heat from the sun to pass; the rays heat the interior, and bodies inside radiate again their heat; but glass is athermanous to heat rays when the source is at 100° or below 100° C.; thus the heat accumulates in the greenhouse. The glass serves as a trap to catch the sunbeams.

Aqueous vapour transmits freely the heat from the sun during the day, but it serves as a screen to prevent radiation at night, being athermanous to heat from sources at a low temperature. (See 'Dew.')

'Remove for a single summer night the aqueous vapour from the air which overspreads this country, and you will assuredly destroy every plant capable of being destroyed by a freezing temperature. The warmth of our fields and gardens would pour itself unrequited into space, and the sun would rise on an island held fast in the iron grip of frost. The aqueous vapour constitutes a local dam by which the temperature of the earth is deepened; the dam, however, finally overflows, and we give to space all that we receive from the sun.'[1]

When radiant heat strikes a body, the heat is broken up into (r) reflected heat, (a) absorbed heat, (t) transmitted heat, (R) radiated heat. Total heat$=r+a+t+R$.

In the case of lampblack $r=o$, $t=o$, $\therefore$ total$=a+R$.

In the case of polished silver $t=o$, $R=o$ nearly, $a=o$ nearly,

$\therefore$ total$=r$ nearly.

76. Intensity.

The intensity of radiant heat varies inversely as the square of the distance from the source. (See 'Light,' 'Sound.')

For an experimental proof of this, see 'Ganot's Physics.'

[1] Tyndall, *Heat a Mode of Motion*.

77. Theory of Exchanges.

Experiments on radiant heat have led to the general adoption of the Theory of Exchanges, first stated by Prevost. This theory states—

That bodies radiate heat at all temperatures, and that the amount radiated depends upon the body itself and not upon surrounding objects; that a red-hot ball radiates the same amount of heat whether placed in the middle of a furnace or hung up in an ice-house; that ice radiates the same whether in an ice-house or hung up in front of a furnace. Bodies also receive heat from surrounding objects. When a body radiates more than it absorbs, its temperature falls; when it absorbs more than it radiates, its temperature rises. If the radiation equal the absorption there is thermal equilibrium and the temperature is constant.

Explain the apparent reflection of cold in § 72

Examples. XXVI.

1. Why is glass used in a greenhouse?

2. Explain Franklin's experiment: he placed several pieces of coloured cloth upon snow when the sun was shining; he found that the darker pieces sank farther than the lighter ones.

3. Polished fire-irons in front of a big fire are cooler than rusted fire-irons. Give the reasons.

4. Is brick or polished steel the best substance for the back of a fire-place?

5. Neglecting the weight, will a helmet of polished brass or one of white cloth be the cooler in the sun's rays? Why?

6. Explain how to determine the emissive powers and the absorbing powers of substances for radiant heat, and state the relations which exist between them.

7. How are the radiation, reflection, and absorption of heat related to one another? Describe the apparatus which has been used to prove the laws of radiation and reflection of heat.

8. Will water boil as quickly in a bright metal kettle as in a kettle that is blackened with use? Which will retain the heat the longer after they are removed from the fire?

CHAPTER X.

WINDS—OCEAN CURRENTS—RAIN—SNOW—DEW.

78. WINDS.

IN Chapter VIII. we learned that in the case of fluids (liquids or gases) with a free surface convection currents could be produced (1) by heating the lower surface or (2) by cooling the upper surface, the result in (1) being that the fluid becomes less dense by expansion, and that a cubic inch weighs less than a cubic inch above it. Gravitation acts and the heavier upper fluid forces its way to the lower position. In (2) the fluid contracts and the cubic inch becomes denser than a cubic inch below it; by gravitation the heavier portion sinks.

The motion of air currents has already been illustrated by the currents in rooms and near heated bodies. The radiant heat from the sun passes through the atmosphere, but little of it being absorbed.

The earth is heated at its surface, land and water receiving the same amount of heat for equal areas. This heating is the greatest at the tropics. The heated earth heats the stratum of air near it, and this is pushed upwards by the denser air from the temperate and polar regions. If there were no motion of the earth, and the earth were a cylinder, there would be a steady wind from the north and the south poles to the tropics.

The earth rotates on its axis from west to east. The air rushing from the north to the equator will not only have a direction to the south, but will also have an easterly direction, due to the motion of the earth at the place it starts from. If it

meet a person as it flows to the south, his speed to the east will be greater than that of the wind; he will therefore cut through it, and it will appear to him as a wind from the north-east. This is the north-east Trade Wind; in the south hemisphere it is the south-east Trade.

The upper current cannot all crush into the small space at the poles; it descends about 30° latitude; its motion to the east is greater than the motion of the earth at 30° N. and it rushes past a person in that latitude as a wind from the south-west (in the southern hemisphere as a wind from the north-west). These form the counter-Trades.

79. Land and Sea Breezes.

The specific heat of water is greater than that of land. Water is a good reflector, therefore a bad absorber of heat and a bad radiator of heat. Land is a bad reflector, a good absorber, and a good radiator. During the day the land absorbs the heat of the sun, and its specific heat being low, the land is soon heated. The sea reflects a great part of the heat, and its high specific heat and its motion cause little alteration in its temperature; evaporation also takes place, and this again keeps down its temperature.

The result is, the heated air rises from the land and a breeze sets in from the sea.

At night the earth radiates rapidly, the sea slightly; soon the temperature of the land falls below that of the sea, and a land breeze ensues.

80. Ocean Currents.

We cannot expect the regularity in the case of ocean currents that we have in the case of winds; the land interferes with their action. Water is a bad conductor; it is therefore probable that the chief cause of ocean currents is the sinking of the cold water at the polar regions (§ 60); this causes a flow of warmer water from the equator. The water at the equator has a high speed towards the east; this would give a general current from the south-west in the northern hemisphere, if no other effect were to be considered. The effect of the north-east Trade Winds

is to give a westerly direction to the current. This tropical current divides; one branch travels south along the coast of Brazil, the other part flows along the coast of Guinea and enters the Gulf of Mexico; it escapes by the narrow opening of the Gulf of Florida, and, urged by the pressure behind, its flow of warm tropical water is forced across the Atlantic Ocean to the shores of Europe. It is doubtful, however, whether the climatic effects attributed to the Gulf Stream are entirely due to it.

81. Rain—Snow—Hail.

The effect of solar heat on the water of the globe is to cause evaporation; the air becomes charged with aqueous vapour, and the mixture of aqueous vapour and air being lighter than air alone (§ 59), the upward tendency of the heated air is aided. As it rises the pressure is reduced; expansion ensues; the heated air, in expanding, does work. This cools the vapour, and it condenses as fine particles of water and forms clouds (§ 29). In condensation heat is liberated; this retards further condensation. If the precipitation of cloud go on rapidly, the particles become larger and descend as rain.

The above explains the heavy rainfall in the tropical regions.

If the current of air charged with aqueous vapour be cooled by any means, by mixing with a colder current or by coming against the cold surface of a mountain, condensation takes place and clouds form; ultimately rain falls. In this condensation heat becomes sensible; thus we have our warm south-west rains.

If the earth be heated so that the air rising is saturated with vapour, the vapour is frequently condensed close to the surface, and forms mists and fogs.

In all cases it is probable that particles of water are only formed from vapour when dust particles are present in the air for the vapour to condense around. And experiments by Aitken show that if the air were free from particles of dust, mist, clouds, and rain could not form.

When the temperature falls below 0° C. the condensed aqueous vapour freezes as small crystals; these crvstals unite and form snow.

Hail is probably formed when rain passes through a cold region of the atmosphere, but no very satisfactory explanation has been given.

82. Dew.

When the air is cooled below the dew-point (§ 55) the aqueous vapour is condensed and is deposited.

The earth radiates at night the heat it receives during the day. This radiant heat scarcely affects the air through which it passes. If the day has been warm the air is saturated with aqueous vapour. The temperature of grass and objects near the ground by radiation falls below the dew point, and dew is deposited. We should expect that good reflectors, being bad radiators, would not readily cool. This is the case; dew is not deposited on bright metal and pebbles when grass and leaves are affected. On cloudy nights the clouds serve as a screen (§ 75), and radiate back to the earth the heat it radiates. Dew is not formed on cloudy nights.

If when dew is forming the temperature fall below 0° C. the vapour is frozen and forms hoar frost. If the dew has first been formed and then frozen the result is black frost.

In India, shallow pans filled with water are placed on straw (a bad conductor) at night. The heat radiates so rapidly from the water that the water freezes.

Examples. XXVII.

1. State what are the conditions favourable for the formation of dew. Describe an instrument for determining the dew point and the method of using it.

2. Explain why the grass in a garden is frequently found to be wet in the morning (though there has been no rain) while the gravel paths are dry.

3. What is the 'dew point'? How is the deposition of dew affected by the presence or absence of clouds in the sky? A table knife with a black handle is left exposed to the atmosphere in the evening; which part of the knife, the handle or the blade, will be first covered with dew? Give reasons for your answer.

4. State the influence of the sun's radiation, and of the rotation of the earth in causing 'Trade Winds.'

5. Explain the production of land and sea breezes. How are the Trade Winds caused?

6. Explain how ice can be formed in India.

CHAPTER XI.

THE MECHANICAL EQUIVALENT OF HEAT.

83. SOURCES OF HEAT.

THE heat used in the experiments in this book has been derived from the following sources :—

(1) THE SUN.—The heat reaches the earth by radiation. We believe that, with light, heat travels in waves.

(2) CHEMICAL ACTION.—The combustion of coal gas has frequently been used ; the burning of fuel is at once suggested ; whenever chemical combination takes place, it is accompanied by heat or by the absorption of heat.

(3) MECHANICAL SOURCES.—(*a*) *Compression* : see the fire syringe (§ 29). (*b*) *Percussion* : by hammering a piece of metal its temperature can be raised ; water in falling down a precipice is heated. (*c*) *Friction* : illustrations are easily found ; a brass button rubbed upon wood, a saw after use, metal plates when punched or sheared, are so hot that they cannot be touched with safety ; bore with a gimlet in a piece of hard wood and feel the gimlet after withdrawal ; the friction at the axle of a railway carriage develops heat sufficient to ignite the woodwork if the axle be not continually lubricated.

(4) CHANGE OF PHYSICAL STATE.—When vapour condenses (§ 54); when liquids solidify and during crystallisation (§ 45).

Other sources are—

(5) ELECTRICITY.—When the current is resisted the heat is sufficient to cause incandescence, as in the case of the electric lamps.

(6) THE EARTH is also a storehouse of heat and supplies the

heat of volcanoes, geysers, and hot springs. The tides are another source of heat.

84. The Nature of Heat—the Mechanical Equivalent of Heat.

The student has been frequently warned that he must not entertain the notion that heat is a fluid with or without weight (whatever that may mean); we have been able to measure heat, to decide upon a unit of heat, and to treat it as a quantity. All that can be done in an elementary work is to repeat the warning. After understanding this book, the reader should study Clerk Maxwell's 'Theory of Heat,' where he will find a complete view of the modern theory 'that heat is a form of energy.' See also the last chapter in 'Light.'

Energy is the power of doing work. The experiments in § 83, par. 3, tell us that when work is done heat is produced; the action of a steam engine tells us, that the heat from the combustion of coal heats the water, and the pressure of the steam moves the piston and does work. The exact relation between the unit of heat and the unit of work was shown by Joule in this way.

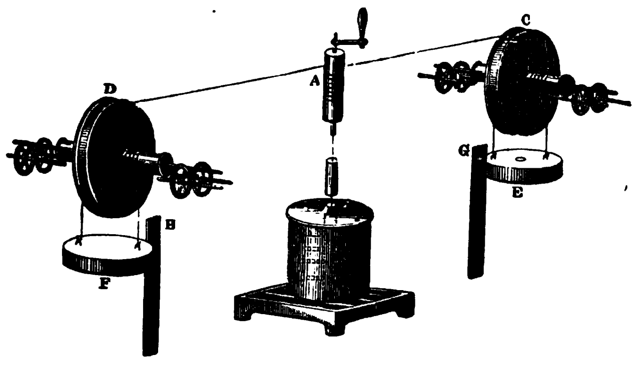


Fig. 53.

B is a copper vessel with a brass paddle wheel—the dotted lines—that rotates when the axis A is turned. A is turned when the weights E, F fall;

the distance they fall is shown by the scales H, G. The cords pass over pulleys as frictionless as possible. The water in B was weighed, its temperature noted; the weights were allowed to fall; they did work in turning the paddle.

The result of the work was to raise the temperature of the water in B. From an enormous number of careful experiments Joule concluded that, on the Fahrenheit scale, the work done by 1 lb. falling 772 feet (or 772 lbs. falling 1 foot) is capable of raising the temperature of one pound of water from 50° F. to 51° F.

772 foot pounds of work is called the mechanical equivalent of heat on the Fahrenheit scale, or the amount of work that must be converted into heat to raise one lb. of water 1° C. is 1390 foot pounds ($\frac{9}{5}$ of 772).

As a foot pound is not a constant quantity but changes with the latitude, it is better to say that the mechanical equivalent of heat is 772 g poundals of work.

Worked Examples.

1. An iron ball weighing 1 lb. falls through 5170 feet; if all the heat generated be communicated to the ball, find the rise of temperature when its fall is arrested. The specific heat of iron = ·114.

The ball does 5170×1 foot pounds of work, or work that would raise 1 lb. of water $\frac{5170}{1390}$ Centigrade degrees of temperature.

Therefore the iron ball would be heated $\left(3 \times \frac{1}{\cdot 114}\right)$ degrees.

Answer: 26·3° C.

2. A mass of zinc falls from a height of 200 feet; through how many degrees F. will its temperature be raised when it strikes the ground, if 75 per cent. of the heat be used in heating the zinc?

The mass in falling would raise an equal mass of water through $\frac{200}{772}$ degree Fahrenheit, if no heat were lost.

The specific heat of zinc is ·095; therefore the zinc would be raised in temperature, $\frac{200}{772} \times \frac{1}{\cdot 095} \times \cdot 75$ degree.

3. A mass of a ton is lifted by a steam engine to a height of 386 feet; what is the amount of heat consumed in this act?

Work done $= 2240 \times 386$ foot pounds. 772 foot pounds raise the temperature of 1 lb. of water through 1 degree Fahrenheit. Therefore the heat consumed would raise 1 lb. of water through $\frac{2240 \times 386}{772}$ degrees; that is, 1120 degrees; or would raise 1120 lbs. of water through one degree.

4. A 100-lb. shot strikes a target with a speed of 1400 feet per second. If all the heat generated by the collision were imparted to 100 lbs. of water at 60° F., how many degrees would the temperature of the water be raised?

The energy of the shot in gravitation units is $\frac{100 \times 1400 \times 1400}{2 \times 32}$ foot pounds.

To raise 100 lbs. of water 1 degree F. requires 100×772 foot pounds of work;

$\therefore$ the water will be heated through $\frac{100 \times 1400 \times 1400}{2 \times 32 \times 100 \times 772}$ degre

EXAMPLES. XXVIII.

1. How high can a mass of 10 tons be raised against gravity, by the expenditure of the quantity of heat, that would raise 1 lb. of water at 0° to 50° C.
2. How much heat is expended in lifting a mass of 1 ton 100 feet?
3. A lead bullet weighing 2 oz. falls 100 feet; by what amount will its temperature be raised when it reaches the ground, if all the heat is expended in heating the bullet? Specific heat of lead = ·03.
4. A waterfall is 336 feet high; if all the heat be used in heating the water, find the difference in temperature between the water at the top and the bottom of the fall.
5. The whole of the heat generated when 60 lbs. of lead falls from a height of 695 feet, is used in melting ice. How much ice will be melted?
6. How did Joule determine the mechanical equivalent of heat?
7. If you were to pour a pound of molten lead and a pound of molten iron, each at the temperature of its melting point, upon two blocks of ice, which would melt the most ice, and why?
8. How many pounds of steam at 100° C. will melt 50 lbs. of ice at 0° C. to water at 0° C.?
9. On the Centigrade scale, find how many thermal units are needed to change 10 lbs. of ice at 0° into steam at 100°.

SOUND.

CHAPTER I.

PRODUCTION AND SPEED OF SOUND.

1. CAUSE OF SOUND.

SOUNDS are produced by the following among other methods :—

Stretch a string tightly and pluck it. The string moves and a sound is produced, which ceases if by any means the motion of the string is stopped (fig. 54).

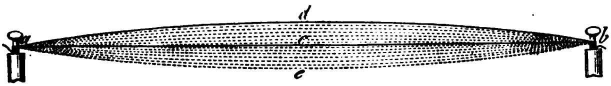


FIG. 54.

Hold a bell jar in one hand ; place a small glass bead in the jar. Strike the jar with a piece of wood ; a sound is heard (fig. 55).

The glass is in motion, shown by the movement of the bead.

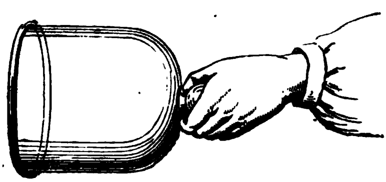


FIG. 55.

Strike a tuning-fork until it gives forth a sound ; hold it so that it touches a glass bead suspended by a thread.

The bead is forced away—the fork is in motion.

Whenever a sound is produced the body producing the sound is in motion.

A body that emits a sound is called a *sonorous body*.

Fig. 56.

Place a glass plate upon a reel; press the centre firmly with the thumb; sprinkle the surface with fine sand. Let an assistant touch the plate at one part, while a violin bow is drawn over another part, until a sound is produced.

The motion of the plate is shown by the beautiful figures described by the sand, which collects along the lines where there is no motion, and moves from the part where the plate is in motion.

By pressing at the point marked C (fig. 57), damping with the finger at *a*, and bowing at *b*, different sounds will be produced, each sound having its particular figure.

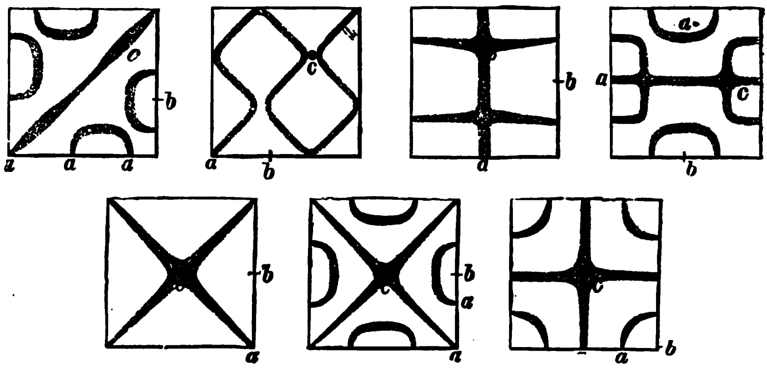


Fig. 57.

In fig. 56 the plate is shown attached to a stand; the simpler method given above is sufficient. Plates of metal will answer better than those of glass.

This method of showing motion in plates was discovered by Chladni.

2. SOUND IS NOT PROPAGATED IN A VACUUM.

The sounds produced are perceived by the ear. How do the sounds reach the ear? Is the presence of air necessary?

Place an alarum clock under the bell jar of an air pump, resting it on cotton wool, or suspending it by silken threads. Set the alarum to ring in five minutes. Exhaust the receiver (fig. 58).

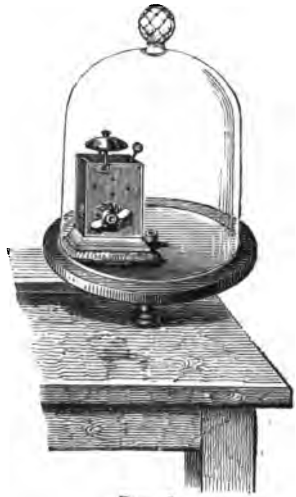


FIG. 58.

The sound of the alarum, when heard, is feeble, and if a good vacuum is produced the sound is not heard at all. Admit the air; the sound gradually increases in intensity.

This can be shown without the aid of an air pump.

Fit a strong flask with a good india-rubber cork, having two holes; pass a piece of glass rod through one hole. To the rod attach a piece of india-rubber tubing; to the end of the tubing attach a small toy bell. Insert the cork, shake, and notice the sound produced. Cover the bottom of the flask with water. Warm carefully, dry the outside, and heat with the naked flame until the water boils briskly. Hold the flask in one hand and a glass stopper in the other.

FIG. 59.

Move the flask from the flame, and at the same instant push in firmly the stopper (fig. 59).

As the flask cools the water vapour condenses and leaves a vacuum.

Shake the flask and compare the sound heard with that when the flask was full of air.

Sound is not propagated in a vacuum.

When the water is cold it will be found difficult to remove the cork. Place the flask on a sand bath until the water is warm; it can then easily be removed.

Dry the flask and hold it over a coal-gas jet; the gas will displace the air. Insert the india-rubber stopper and ring the bell. The sound is much fainter than when filled with air.

The result is more marked if it be filled with hydrogen gas.

Fill the jar with carbonic acid gas. This gas is heavier than air (coal gas and hydrogen are lighter than air). The sound is louder than in air.

The loudness depends on the density of the gas in which the sound originates, not upon the gas (air) surrounding the person who hears the sound.

The air on mountain-tops is less dense than the air in the valleys: sounds produced on the former are enfeebled; a pistol-shot sounds like the report of a good popgun. If, however, a cannon be fired in the valley, the sound as heard by two persons each half a mile off, one on the top of a mountain and the other farther down the valley, will be of the same intensity.

3. Speed [1] of Sound in Air.

The flash of lightning is seen before the sound of thunder is heard, though both occur simultaneously.

The flash of a cannon precedes the report. If a sea target, a cannon, and a spectator be placed at corners of an equilateral triangle, the spectator sees first the flash, then the column of water caused by the shot striking the sea, and last of all hears the report. Thus a person within range would

[1] Speed is the rate of motion. The speed of a point is called its velocity when the direction in which it is moving is taken into account. The two terms are frequently used synonymously.

have no intimation of danger, by the report preceding the shot.

The speed of sound in air is, therefore, less than the speed of light, and less than the speed of a cannon ball.

To Measure the Speed of Sound in Air.

The distance between two places is exactly measured. At station A a cannon is fired; at station B the observer notes how long after seeing the flash the report is heard. A cannon is now fired at B, and the time is taken at A. The average of several results is taken.

Two stations were 61,045 feet apart; the report was heard 54·6 seconds after the flash was seen.

Speed of sound in air $= \frac{61045}{54 \cdot 6}$ feet per second $= 1118$ feet per second.

This assumes, that the time it takes light to travel any ordinary distance is so small, that it can be disregarded. (Light travels 20 miles in $\frac{1}{9300}$ of a second.) By firing cannon at both stations, and taking the average, the action of the wind is allowed for.

The observers obtained different results according to the temperature; the higher the temperature the greater the speed. At 0° C. the speed is 1090 feet per second; 2 feet can be added for every degree. At 15° C. (ordinary temperature) the speed is $(1090+30)$ feet per second; that is, 1120 feet per second.

Changes in the barometer did not affect the results.

Ordinary observations show that all sounds travel at the same rate; otherwise it would be impossible to distinguish a tune played by a band at a distance. The sounds would mix.

Certain observations in the Arctic regions show that a loud sound travels quicker than a gentler one. The report of a cannon was heard before the word of command to fire.

4. Speed of Sound in Water.

Two boats were stationed on Lake Geneva a measured distance apart. One boat had a bell C under water (fig. 60);

this was struck by a hammer *b*, the hammer being worked by a lever *a*, which at the same time moved the lighted wick *e*, so that it ignited the gunpowder *m*. The observer in the other boat, fixed the end *o* of a bent trumpet in his ear, the open part, *fg*, being turned towards the bell; the flash of the gunpowder announced when the bell was struck, and the observer noted the time that elapsed before the sound reached him.

The stations were 51,700 feet apart, the sound was heard 11 seconds after the flash was seen.

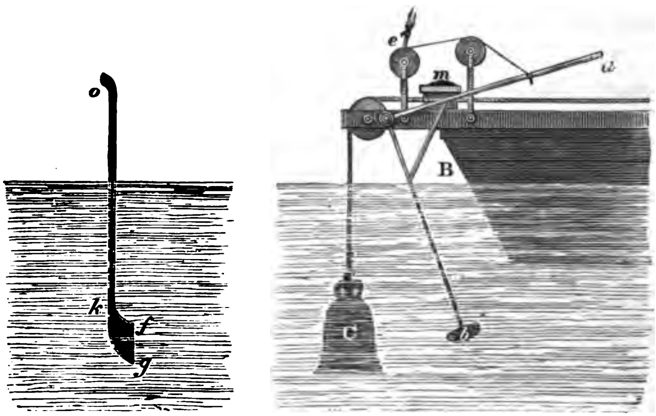


FIG. 60.

∴ speed of sound in water=4700 feet per second. The average results give a speed of 4708 feet per second; that is, 4 times the speed in air.

Changes of temperature have not a marked effect upon the speed of sound in water.

LIQUIDS TRANSMIT SOUND.

On the sound-board place a dish of mercury; dip into this a glass tube a foot long, closed at one end. Pour water into the tube. Strike the tuning-fork; the sound is feeble. Put the stem into the water; at once the sound is reinforced. The stem of the fork should be fixed into a conical piece of cork or wood.

The sound waves travel through the liquids, and give up the vibrations to the board; this communicates them to the air.

5. Speed of Sound in Solids.

It is a common experiment for one person to place his ear against a telegraph post, while another strikes the next post with a stone. Two sounds are heard, the first conducted by the wire, the second conducted by the air. The first sound is the more distinct.

Sounds travel quicker in solids than in air, and are conveyed with greater intensity.

Remove the lids from two cigar boxes, bore a hole in the bottom of each, pass the end of a cord through and tie it to the end of a piece of twisted wire. Stretch the cord; use fifty yards, or, better, 100 yards. Hold the boxes so that the bottoms are towards each other.

The slightest tap or scratch on one is distinctly heard if the ear be placed against the other. Place a vibrating tuning-fork near one. Sounds that usually cannot be heard at that distance, are distinctly heard when the sound is transmitted by cord; better results are obtained by using wire. Bending the cord round posts, or corners, does not interfere with the success of the experiment.

The speed of sound in solids is so great, that methods similar to those for determining the speed in air and water, cannot be used with accuracy. Biot, by experimenting upon the cast-iron water pipes in Paris, concluded that sound had a mean speed of 3250 metres per second. The other methods used will be given later.

The speed of sound—

(1) In air at $0° =$ 1093 feet per second
(add 2 feet for every degree Centigrade)
(2) In water = 4780 feet per second.
(3) In copper = 11666 " "
(4) In iron = 16822 " "

A body that produces sound is in motion and is called a sonorous body.

EXAMPLES. I.

1. How would you show that sound is not transmitted by a vacuum?

2. Give some familiar evidence that sounds of all kinds travel nearly at the same rate.

3. Describe any experiment which occurs to you, for showing that sound is capable of being transmitted through liquids.

4. Explain in what way, the velocity of sound in water has been experimentally determined.

5. You see a flash of lightning, and you hear the thunder which follows. Supposing the velocity with which the sound of thunder travels through the air to be known, how would you determine the distance of the lightning flash?

6. The temperature on a certain day is 15°; the report of a gun is heard 6 secs. after the flash is seen. How far is the spectator from the gun?

7. Explain the action of the 'toy telephone,' made of two cardboard boxes connected with string.

8. Standing some distance from a quarry, I hear two sounds following the blow the workman gives to the rock. Explain this.

9. Give experiments to show that sound is produced by motion.

CHAPTER II.

WAVE MOTION—ELASTICITY.

6. HARMONIC MOTION—VIBRATION—AMPLITUDE.

WHEN a stone is thrown into a pond, waves proceed from the point where the stone falls, to the margin of the pond. Pieces of wood or leaves, that may be floating in the water, are not washed to the bank; they simply move up and down; if a patch of water be blackened with ink, the wave in moving over the patch does not force it onward. The wave moves forward; the particles of water that form the wave, apparently move up and down. Waves cross a field of long grass; the tips of the grass blades do not move onward; the *form of the wave* alone moves forward. In the absence of currents, a bather in the sea is not washed ashore by the waves. A bargeman, when he wishes his rope to clear an obstacle, sends a wave along it; the rope itself does not move forward.

Fill the long trough with water; by mixing wax and iron filings pellets can be formed that will float at various depths. With a piece of wood start a wave from one end; the balls describe small circles or ellipses, but their *average position* does not change.

Fasten a leaden bullet to a fine piece of cord suspended from a hook, so that the distance from the point of suspension to the centre of the bullet is thirty-nine inches. Set it swinging; note the time it takes to move sixty times from side to side; the time will be about one minute. A motion from side to side is called an OSCILLATION; a motion *from one side to the other and back again* is called a VIBRATION. The pendulum vibrates once every two seconds, and oscillates once per second.

By giving the bullet the necessary impetus, set it swinging at

a regular speed in a horizontal circle ; count how many circles it completes in 20 seconds ; the number will be about 10. It completes 1 revolution, in the time it took to make a vibration in the first experiment. Place the eye so that the circle appears a straight line, and observe the motion.

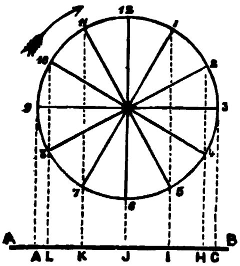


FIG. 61.

The bullet increases its speed in the line from each end, until it reaches the middle ; then it slackens until it reaches the far end of the line, when it momentarily stands still, returns, again quickening up to the middle.

Let the circle in fig. 61 represent the plan of the path of a pendulum, the line A G the elevation of the path. A G is equal to the diameter of the circle. Suppose the time of one revolution to be one second. Divide the circumference into 12 equal parts. The pendulum moves over each part of the circumference in $\frac{1}{12}$ of a second. Therefore, to an observer who sees the *elevation*, the pendulum moves over each of the spaces A L, L K, K J, etc., in $\frac{1}{12}$ of a second ; the speed increases towards the centre.

When a body vibrates along a line, as the bullet appears to vibrate along A G, the motion is called HARMONIC MOTION.

We can always find the position of a pendulum by drawing the circle, dividing it into equal parts, and obtaining the points L, K, J, etc., on a diameter.

The distance A G (the diameter of the circle) is called the AMPLITUDE *of the vibration.*

The time of moving from A to G *and back again to* A—that is, the time of a complete revolution of the circle—is called THE PERIOD of the vibration.

In an ordinary pendulum, if we place the eye beneath it, so that its path appears a straight line, the motion appears harmonic.

7. WAVES—WAVE LENGTH.

Suppose we have a number of particles, moving in parallel straight lines, A, B, C, etc., at equal distances apart, *moving*

with harmonic motion, so that each succeeding particle begins to move $\frac{1}{12}$ of a second behind the other.

Draw the circle, divide it as before, draw the dotted lines parallel to the diameter 9—3. Suppose the particle to move in the circle in the same direction as the hands of a watch. Suppose the

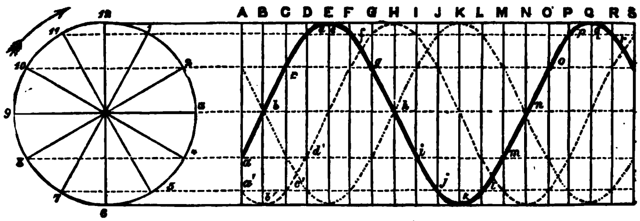


FIG. 62.

particle in A at *a*, i.e. at 4 in the circle. The particle in B is $\frac{1}{12}$ sec. behind; it is therefore at 3, and will appear in B at *b*; C is $\frac{2}{12}$ sec. behind, and will appear in C at *c*, and so on for *d e f* . . (fig. 62).

Join these points with a curve. This sinuous curve would appear to the eye as a wave.

What will be the condition $\frac{3}{12}$ second later? *a* will have moved from 4 to 7 and will appear on A at *a'*; *b* will have moved to *b'*, and the dotted curve *a' b' c' d'* is formed; the *form of the wave* is moving from A to S. The wave indicated by – ·· – ·· – is the position $\frac{6}{12}$ second later; in $\frac{12}{12}$ second the particles will be in their original position, but the wave will have moved forward from E to Q or from A to M.

The student should study carefully the drawing, *after he has drawn it himself.*

The top of a wave is called the CREST, the hollow the TROUGH.

The distance from crest to crest, or from hollow to hollow, is called a WAVE LENGTH. A WAVE LENGTH, *is the distance from any particle, to the next particle that is in a similar position in its path, and is moving in the same direction.*

Take the particle *c*; *g* is in the same position, but when *c* is moving downwards *g* moves upwards; *o* is the next particle in

the same position, and as *c* moves downwards *o* moves downwards; from *c* to *o* is a wave length.

How long does it take the wave to travel from E to Q?

In $\frac{1}{4}$ period the crest is at H,
" $\frac{2}{4}$ " " " K,
" $\frac{3}{4}$ " " " N,
" $\frac{4}{4}$ " " " Q.

The distance the wave travels in one period is one WAVE LENGTH.

Particles may also move in circles or ellipses. Fig. 63 illustrates this. Suppose a number of particles, 0, 1, 2, 3, at rest, then imagine that 0 begins to move in a circle, its period (time of one revolution) being 1 second. Each particle moves $\frac{1}{12}$ second later than its predecessor.

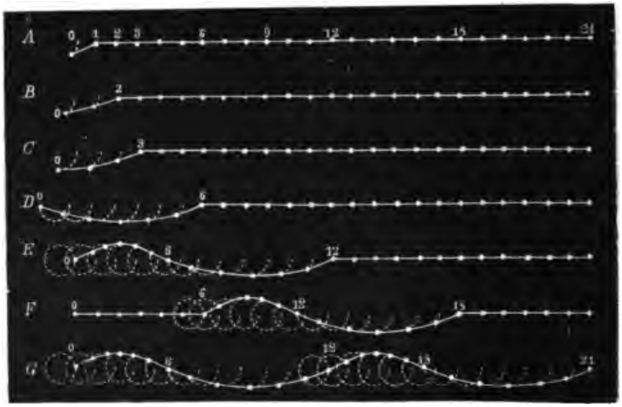


FIG. 63.

A is the position at the end of $\frac{1}{12}$ period,
B " " " $\frac{2}{12}$ "
C " " " $\frac{3}{12}$ "
D " etc. " " $\frac{6}{12}$ "
(0 has described a semicircle).
E is the position at the end of $\frac{12}{12}$ period.

In E, 0 and 12 are in the same position and are moving in the same direction; therefore from E to 12 is a wave length.

If, after one revolution, the particles rest, then $\frac{6}{12}$ period after o rests, F represents the position—the wave has moved *half a wave length*; if each particle keeps moving, the waves are repeated as in G.

Cut a slit $\frac{1}{16}''$ wide in black paper (fig. 64, B), place it over the line S in fig. 62, draw the book beneath the slit, and the motion of a particle in harmonic motion will be seen. Blacken a piece of glass, rule a number of parallel lines 1″ long and $\frac{1}{8}''$ apart with a needle. Place this over the curve, and draw the curve beneath.

The *wave form* will pass across the glass.

Blacken a long strip of glass 18″ long by $1\frac{1}{2}''$ wide; with a fine point draw a sinuous curve. On a square of glass 3″ size draw a number of parallel lines 1″ long, about $\frac{1}{8}''$ apart; place the strip behind the square so that the lines are vertical; hold both to the light, draw the strip across. A wave will be seen crossing the glass. Protect the blackened part with thin glass. Place the square in a magic lantern as an ordinary slide, the strip in front of the square; focus the dots and draw the strip across the square: a wave will pass across the screen.

In all these illustrations, it is seen that, in wave motion, the particles do not change their average position; the form of the wave alone moves forward.

Draw another sinuous curve whose amplitude (vertical distance from highest point to lowest point) is one half of the first. (Use the same construction, but make the diameter of the circle one half.) With this, and the square with ruled lines, produce a wave. The wave travels *as quickly* as before, but the crests and hollows are not so marked; the *amplitude* then does not affect the speed, it affects the power of the wave.

EXAMPLES. II.

1. Give an example of harmonic motion.
2. Define the terms oscillation, vibration, amplitude, period.
3. Give examples of wave motion. Explain crest and hollow.
4. Define wave length.
5. In what direction do the particles in a water wave move?
6. There are five crests between a boat and the shore, a distance of 100 feet. Calculate the average wave length.

8. Longitudinal Waves.

The preceding explains water waves, the waves that pass along ropes, and, as we shall see later, the waves of light. There is, however, another method by which waves can be transmitted.

Hang a piece of india-rubber tubing 12 feet long from the ceiling; near the top make a distinct chalk mark; hold the end to

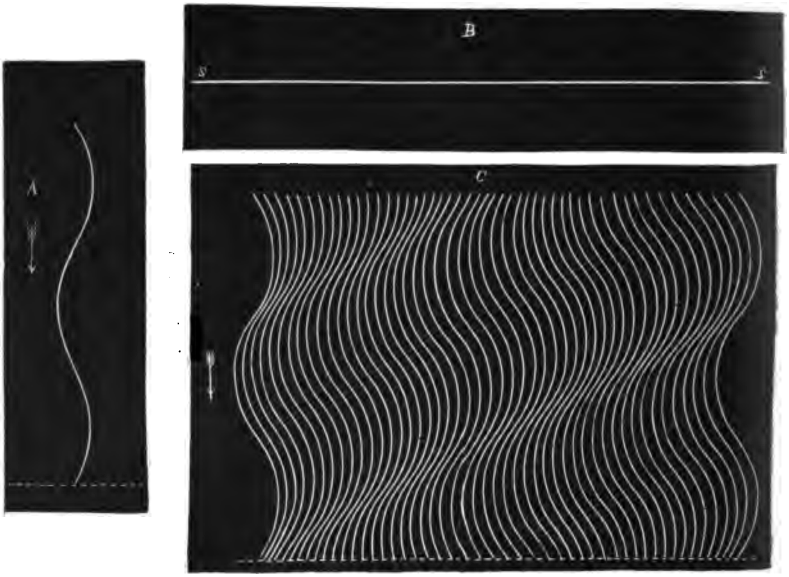


Fig. 64.

stretch slightly the tube; with the fingers of the other hand, rub it along its length.

A wave passes up the tube, as is shown by the movement of the mark; it is reflected at the top and moves back.

Wrap iron wire round a piece of glass tubing, so that the coils touch; on removing it a spiral is formed; fasten one end to any point, hold the other in the hand to *slightly* stretch it, with the

edge of a knife rub smartly against three or four coils in the direction of the length.

The compression travels along the tube; it can be easily observed by fastening pieces of straw with sealing-wax to parts of the wire.

In *water waves* the particles move *across the line of direction*; in the waves in the tube and the spiral, the particles move *backwards and forwards in the line of direction.*

Cut a narrow slit *s s*, in black paper (fig. 64, B); place it along the dotted line of A. Draw A beneath the slit in the direction of the arrow; the dot that is seen, vibrates backwards and forwards; its motion is harmonic, as we see from the sinuous curve.

A number of dots moving backwards and forwards, one moving *a little after the other*, will produce a wave; there will be a compression (the particles come together) succeeded by a rarefaction (when the particles move apart, relative to each other), like the compression and rarefaction that travelled along the coil. Place the slit along the dotted line in C (fig. 64); draw the book in the direction of the arrow.

Each curve in C is similar to A. They are arranged so that each dot produced with the slit, moves a little later than the preceding dot.

The *wave* will be seen travelling across the slit.

Compare the parts of greatest compression with crests of waves, the parts of rarefaction with troughs of waves (fig. 65).

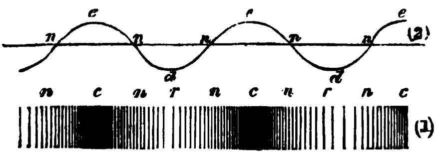


Fig. 65.

The wave length is the distance from one compression to the next, or one rarefaction to the next, or from one particle to the next particle, in a similar position and moving in the same direction; and, as before, the wave will move one wave

length, in the time it takes one particle to make a complete vibration.

Examine and use this excellent diagram of Professor Weinhold carefully; it will give a better idea of the wave of compression and rarefaction, than a page of words.

9. Sound Waves.

Sound waves are transmitted by the air particles vibrating in the line of direction.

When a gun is fired the sound travels; there is, however, no tendency for the smoke to move in all directions in straight lines, as the sound does.

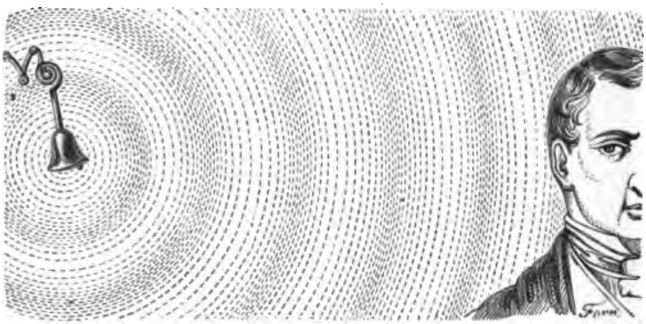


Fig. 66.

This can be illustrated by fixing a funnel to one end of a long, wide india-rubber tube. Direct the other end towards a lighted candle, and blow a little smoke into this end. Fire a pistol across the mouth of the funnel; the candle is extinguished by the sound wave, but the smoke is not forced through the tube. Such sound waves from firing shots in mines, it has been suggested, cause explosions, by forcing impure gas through the meshes of the Davy lamp.

Sound travels in all directions. A skylark singing is the centre of a sphere of sound waves, and every particle in the sphere is vibrating.

The propagation of a sound wave is not the propagation of air particles.

Fig. 66 gives a rough idea of the sound waves caused by a bell.

At equal distances from the point of disturbance all the particles will be in similar positions, and these particles will form the surface of a sphere; such a surface forms the *front* of the wave. If we consider a small portion of the surface of a large sphere, it will practically be a plane surface. So that the *wave front* is a plane surface, and the *direction* of the wave is at right angles to this surface.

A tuning-fork vibrates 256 times in a second; in 1 second the sound has travelled at ordinary temperatures 1120 feet. If an observer be at this distance, there must be, between the ear and the fork, 256 condensations and 256 rarefactions.

A condensation and a rarefaction make up one undulation or wave length;

$\therefore$ one wave length of a fork vibrating 256 times in 1 second $= \frac{1120}{256}$ feet $= 4{\cdot}4$ feet, nearly.

If the fork be placed on a rod of iron, the sound travels 16,800 feet per second,

$$\therefore \text{ wave length in iron} = \frac{16800}{256} \text{ feet} = 65{\cdot}6 \text{ feet.}$$

The wave length has nothing to do with the distance moved over by the particles; it depends upon the period of their vibration.

10. Elasticity.

Set a dozen solitaire balls in a groove; move one and roll it against the eleven; the end one starts off the row, while he intermediate balls are motionless.

In the water waves, the particles moved upwards on account of the impulse given to the wave (the stone falling in the pond, etc.), and downwards on account of the action of gravity. How can we explain, that when a particle moves forwards it returns on its path and moves backwards? Why do the solitaire balls transmit the waves?

Definition.—*When a body, after being compressed by a force, recovers its original shape when the force is removed, the body is said to be elastic.*

If a piece of putty be compressed, it requires a certain force to compress it, but on removing the pressure, the original shape is not regained. Putty is inelastic.

Cover a flat stone with red powder; touch it with a solitaire ball and notice the dot made. Allow the ball to fall from a height of three or four feet upon the stone, and examine the dot made; it is larger than before: the ball has been flattened, but when the pressure was removed it regained its original shape.

The glass ball is elastic. Allow a leaden ball to fall; the flattening remains: lead is inelastic.

If a tuning-fork be set vibrating, every time one prong advances it gives a push to the air; the particles are compressed, and by their elasticity resist compression; they expand, compressing the next set of particles; these in their turn compress the next set, so that a compression is propagated. When the prong moves back it causes a rarefaction; this rarefaction is transmitted in the same way. The tuning-forks make a series of backward and forward movements, and thus a series of condensations and rarefactions are produced, which constitute sound waves.

The particles recover themselves on account of their elasticity.

Suppose we have a body, whose volume is V, subjected to a pressure P per unit of area over its whole surface. Let the pressure be increased by a quantity p, and the volume consequently decreased by a quantity v.

New volume $= V - v$. New pressure $= P + p$.

$\frac{v}{V}$ is the compression in volume per unit volume, due to the increase of pressure p. Therefore $\frac{v}{V} \div p$ is the compression per unit volume due to unit increase of pressure. This is called the compressibility of the body.

Definition.—The reciprocal of the compressibility, that is, $p \div \frac{v}{V}$, is called the elasticity of a body.

11. In Gases Elasticity Equals the Pressure.

A *small* increase in the pressure (p) causes a change in the volume (v). p and v are small compared with P and V. By Boyle's law ('Heat,' § 26)

$$(V-v)(P+p)=V\times P;$$

$$\therefore \frac{P+p}{P}=\frac{V}{V-v};$$

$$\therefore \text{ by division, } 1+\frac{p}{P}=1+\frac{v}{V}+\frac{v^2}{V}+\frac{v^3}{V} \text{ etc.}$$

v is *very small*, $\therefore v^2$ is very small, much smaller $\frac{v^2}{V}$;

$\therefore$ we can neglect $\frac{v^2}{V}$, $\frac{v^3}{V}$, etc., without making any appreciable error.

$$\therefore 1+\frac{p}{P}=1+\frac{v}{V};\ \therefore \frac{p}{P}=\frac{v}{V}.$$

By definition $p\div\frac{v}{V}=$ elasticity; $\therefore p\div\frac{p}{P}=P=$ elasticity.

In gases that obey Boyle's law the elasticity is equal to the pressure.

Examples. III.

1. Compare the direction of the motion of the particles in a water wave, and the wave in a wire spiral.

2. Define wave length. Suppose the amplitude of vibration of the particles be doubled; how will this affect the wave length?

3. Explain undulation, condensation, and rarefaction.

4. Give illustrations and experiments to show that when a sound wave is transmitted, the air particles do not leave their average position.

5. Explain elasticity; give examples of elastic and inelastic substances.

6. Explain how the condensation and rarefaction constituting a wave of sound are produced. How is a sound wave propagated through air?

7. What is meant by elasticity as applied to gases? The barometer stands at 31 inches; what is the elasticity of the air equal to? What is a pressure, and how is it measured?

8. Take the speed of sound as 1120 feet per second. Find the wave length, (*a*) if there be 280 vibrations per second, (*b*) if the period of the particles be $\frac{1}{440}$ second.

9. Sound waves are 1·2 foot long; the air particles make 1000 vibrations in a second. Find the speed of sound

CHAPTER III.

NEWTON'S FORMULA—LAPLACE'S CORRECTION.

12. To Calculate the Speed of Sound in Air.

Sir Isaac Newton, from calculations, concluded that the speed of sound in any substance could be obtained from the formula

$$v = \sqrt{\frac{E}{D}}.$$

$v =$ speed, E = elasticity, D = density.

Take the centimetre, the gram, and the second as units.

In a perfect gas the elasticity equals the pressure.

$\therefore$ formula for a gas becomes $v = \sqrt{\frac{P}{D}}$.

Let the temperature be 0° C. and the barometric height be 76 c.m. Then the pressure equals the weight of 76 cubic centimetres of mercury per square centimetre. The mass of 1 cub. cm. of water is 1 gram. The density of mercury compared with water is 13·6. The accelerative force of gravity = 981 centimetres per second in every second.

$$\therefore \text{elasticity} = 76 \times 13{\cdot}6 \times 981 = 1013961 = P.$$

D = density, is the mass of one cubic centimetre of air

This equals ·001293 gram.

$$\therefore v = \sqrt{\frac{1013961}{\cdot 001293}} = 28359 \text{ centimetres per second.}$$

Actual experiment makes the velocity 33,000 centimetres per second.

Such a difference between CALCULATION and FACT showed that some error had been committed in the calculation.

Newton in his calculation allowed for the fact, that when a gas is compressed, its elasticity is increased, because its density is increased. If we compress a gas very slowly, so that the heat is allowed to escape, the temperature does not rise, and this increase of elasticity, due to increase of density, is the only increase to allow for. But by the fire-syringe experiment, ('Heat,' § 29) it was seen that if the gas be compressed suddenly, heat is evolved, and this heat increases the elasticity—that is, an increased pressure must be applied to keep its volume constant. Similarly it was seen that if a gas be suddenly rarefied the gas is cooled, and this lowering of temperature lessens the elasticity.

What takes place when sound travels in air? Is the air heated? The particles are suddenly compressed at the condensed part of the wave, and are therefore heated. The particles are suddenly separated at the rarefied part of the wave, and are cooled as much as they were heated at the condensed part; therefore the *average* temperature remains the same. Has this any effect on the speed of the wave? (See fig. 65). The particles at *c c* are heated, their elasticity is increased; they therefore tend the more to separate, they separate the more rapidly, and thus the speed of the wave is increased. Condensation is succeeded by a rarefaction, and the rarefied part is cooled. Its elasticity is reduced; therefore the condensed particles in front are the more easily able to rebound, and again the speed of the wave is increased.

Taking into account this difference, Laplace found that Newton's formula should be

$$v=\sqrt{1{\cdot}41\,\frac{E}{D}}=\sqrt{1{\cdot}41\,\frac{P}{D}}.$$

(See 'Heat,' § 43.)

13. CONSIDERATION OF $v=\sqrt{1{\cdot}41\,\frac{E}{D}}=\sqrt{1{\cdot}41\,\frac{P}{D}}$.

(1) *Suppose the pressure change.*—Let the barometer change from 30 to 31 inches. If D be density when the barometer is at 30

then $D \times \frac{31}{30}$ is the density when the barometer is at 32. The density changes in the ratio 30 to 31. The elasticity also changes in the ratio 30 to 31. Therefore the value of $\frac{P}{D}$ does not change.

That is, change of pressure causes no change of speed; it affects E *and* D *in the same ratio.*

(2) *Suppose the temperature change, say from* 15° *to* 20°. If D be the density of a gas at 15°,

$$\text{by Charles' law the density at } 20° \text{ is } D \times \frac{273+15}{273+20} = D \times \frac{288}{293};$$

that is, the denominator in the formula becomes less; E does not change, $\therefore v$ becomes greater.

A rise or fall of temperature causes a rise or fall of the speed.

For each rise of 1° C., from 0° C., add 2 feet to the speed of sound in air.

(3) *To compare the speed of sound in two gases under the same pressure.*

The densities of hydrogen and oxygen are as 1 to 16.

$$\frac{\text{speed of sound in H}}{\text{speed of sound in O}} = \sqrt{1{\cdot}41\frac{P}{D}} \div \sqrt{1{\cdot}41\frac{P}{16\,D}}$$

$$= \sqrt{\frac{1}{D}} \div \sqrt{\frac{1}{16\,D}} = \sqrt{\frac{16}{1}} = \frac{4}{1}.$$

That is, the speed is four times greater in hydrogen than in oxygen.

The speed of sound in two gases, is inversely as the square roots of their densities.

14. Speed of Sound in Liquids and Solids.

[The speed is determined by the formula $v = \sqrt{\frac{E}{D}}$.

The correction applied by Laplace to gases is not a measurable quantity, in the case of solids and of liquids. Density is mass of unit volume.

Elasticity in Solids.

A rod whose length is L feet and A square inches in section is stretched by a mass of W pounds ; it lengthens l feet.

$$\frac{W}{A}g = \text{stretching force in poundals per square inch}$$

$$\frac{l}{L} = \text{elongation per foot.}$$

$\frac{l}{L} \div \frac{W}{A}g$ is the longitudinal compressibility, and therefore

$$\frac{W}{A}g \div \frac{l}{L} \text{ is the longitudinal elasticity.}$$

In solids $\frac{W}{A}g \div \frac{l}{L}$ is called Young's modulus of elasticity (μ) ; this differs in various metals, etc.

In the propagation of sound, along a solid in the form of a rod, the sides are free to expand or contract, so that the only change of volume to be noticed is that in the direction of the length.

Young's modulus $= \mu = E$ in the above formula.

EXAMPLE.

The modulus of elasticity, in gravitation units, in wrought iron is 28,450,000 lbs. per square inch. One cubic foot weighs 488 lbs. Find the speed of sound in iron.

$g = 32$ feet per second in every second.

Attend to units. $\mu = (28450000 \times 144)\, g$ poundals per square foot.

D = 488 pounds.

$$\therefore\ v = \sqrt{\frac{28450000 \times 144 \times 32}{488}} \text{ feet per second}$$

$$= 16392 \text{ feet per second.}$$

If by any other means v could be found, then by the formula μ could be calculated.

Elasticity in Liquids.

When unit volume is subjected to a pressure, a slight diminution takes place. This diminution is called the compressibility (μ) for the given pressure.

If W be the mass causing pressure, evidently E in liquids =

$$\left(Wg \div \frac{\mu}{1}\right).$$

EXAMPLE.

When water is subject to a pressure of 10333·3 kilogrammes per square metre, the compressibility equals ·00005. Find the speed of sound in water.

1 cubic metre of water at 4° C. weighs 1000 kilog.

$g = 9{\cdot}81$ when metre and seconds are the units;

$$\therefore\ v = \sqrt{\frac{\mathrm{E}}{\mathrm{D}}} = \sqrt{\frac{10333{\cdot}3 \times 9{\cdot}81}{{\cdot}00005 \times 1000}} \text{ metres per second}$$

$$= 1424 \text{ metres per second.}$$

The actual measurements on Lake Geneva gave 1435 metres per second.]

EXAMPLES. IV.

1. Explain how to determine the velocity of sound in a solid, and state clearly on what properties the velocity depends.

2. Sound is said to travel four times as fast in water as in air. How has this been proved? State your reasons for thinking whether sound travels faster or slower in oil than in water.

3. Explain why the rise of temperature, due to compression, and the fall of temperature, due to rarefaction in a sound wave, both tend to increase the velocity of propagation of the wave.

4. A tube, 1000 feet long, is filled with oxygen gas. Find how quickly the sound of a pistol-shot will travel from one end of the tube to the other, it being given, that the density of the oxygen is 16 times as great as that of hydrogen, and that the velocity of sound in hydrogen is 4200 feet per second.

5. Give Newton's formula for determining the speed of sound in a gas. How did Laplace correct this formula?

6. The velocity of sound in a liquid is said to depend on the ratio of its elasticity to its density. State clearly what you mean by the elasticity of a liquid. Does sound travel in water quicker than in quicksilver? Give reasons for your answer.

7. What is meant by elasticity in a solid? The modulus of elasticity of copper is 1,250,000 kilog. per sq. cm. One cubic cm. of copper weighs 8·9 grams. Find the speed of sound in copper.

CHAPTER IV.

INTENSITY, REFLECTION, AND REFRACTION OF SOUND.

15. INTENSITY OF SOUND.

THE farther the ear is from a sonorous body the feebler is the effect as regards sound upon the ear.

Suppose a skylark high above the earth gives one sharp chirp. As the sound wave travels, it will pass over surface after surface of concentric spheres, whose centres are at the skylark.

(*a*) Surface of sphere[1] of 1 foot radius $= 4\pi$
(*b*) " " 2 feet " $= 16\pi$
(*c*) " " 3 " " $= 36\pi$

Each surface receives the same amount of sound.

$$\therefore (A) \text{ 1 square foot of } a \text{ receives } \frac{\text{amount of sound}}{4\pi} = \frac{A}{4\pi}$$

$$(B) \text{ 1 square foot of } b \text{ receives } \frac{\text{amount of sound}}{16\pi} = \frac{A}{16\pi}$$

$$(C) \text{ 1 square foot of } c \text{ receives } \frac{\text{amount of sound}}{36\pi} = \frac{A}{36\pi}$$

A, B, C, are proportional to $\frac{1}{1}, \frac{1}{4}, \frac{1}{9}$, that is $\frac{1}{1^2}, \frac{1}{2^2}, \frac{1}{3^2}$.

That is, the INTENSITY OF SOUND *is inversely as the square of the distance from the sonorous body.*

[1] The surface of a sphere $= 4\pi r^2$.
$\pi =$ circumference of a circle $\div$ diameter.
$r =$ radius of sphere.

When a water wave passes from the centre of a pond, its height decreases as it progresses.

The intensity of sound depends upon the amplitude of the particle of the sound wave; it increases or decreases as *the square of the amplitude.*

The *intensity* also depends upon the *density of the medium* in which the sound originates (§ 2).

Make the tuning-fork sound, then place the end upon the table or, better, on a thin board suspended by threads; observe how the sound is increased. Sprinkle fine sand upon the thin board; the sand moves, proving that the board is vibrating.

The *intensity* depends upon the *area of the sonorous body.*

A string stretched tightly over two nails in the wall, when vibrating produces scarcely any sound. Stretch the same string on supports, inserted in a box with a thin cover; the sound is increased; it is the thin wood vibrating that increases the intensity. This is why musical instruments are provided with sounding-boards. In the violin the thin wood forming the belly, vibrates when the string is bowed; the post communicates the vibration to the back, which also vibrates.

Wrap a watch, or a musical box, or an alarum clock in folds of flannel until no sound is heard; insert a piece of wood pointed at both ends, until one end touches the instrument; still no sound is heard; fasten to the end of the rod outside the flannel a square foot of thin wood. The surface is now large enough to communicate the vibrations to the air, and the sound is distinctly heard.

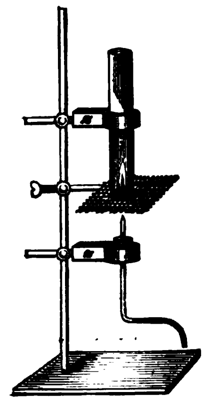


FIG. 67.

16. REFLECTION OF SOUND.

A SENSITIVE FLAME.—Bend a piece of glass tubing at right angles. Draw out one end, cut off, so as to leave a very small orifice. Connect the other end with the gas supply; 2″ above the orifice place a square piece of brass gauze 6″ side; turn on the gas, ignite it above the gauze, and surround the flame with a wide piece of glass tubing about 6″ long (fig. 67). Turn the gas tap until the

flame just *does not flare.* The sound waves affect the gas below the gauze and the flame flickers.

Rattle keys, tap on the table, hiss, whistle; the flame is at once affected.

Arrange the tin tubes as in fig. 50. Remove the tin-plate reflector. Place the sensitive flame in the position occupied by the differential thermometer; tap two pieces of metal together inside the other tube (in the position of the copper ball). Place a screen of several damp towels between the flame and the pieces of metal.

Adjust the flame (use more damp towels if necessary) until it does not respond to the taps.

Place the reflector in position; the flame is at once affected. The sound wave has travelled down the tube, has been reflected from the tin plate and passed down the other tube. Remove the plate; the flame steadies. Instead of the plate use a sheet of paper, the palm of the hand, a broad gas flame. Remove the damp towels and try dry towels, sheets of paper, and compare the absorbing powers of these bodies.

In using this sensitive flame the taps made are more suitable than a whistle or pipe; the flame is so sensitive that there is a little difficulty in reducing its sensitiveness. By attending to the instructions the experiments will succeed.

Determine the position of the focus of the concave mirror ('Light,' § 19). Place the sensitive flame in position, tap at a distance of 20 or 30 feet, and arrange so that the flame just does not respond. Place the mirror so that the flame is now at its focus; at once it answers (at a distance of 30 feet the conjugate focus is practically at the focus). Sound is reflected according to the laws of reflection of light and heat. See these laws.

Substitute a watch for the 'taps' and the ear for the sensitive flame, and experiment again if necessary.

Refer to 'Heat,' § 72, and perform analogous sound experiments.

17. Speaking-Tubes.

Reduce the flame (or use a watch) until it is not affected by taps at a distance of 10 feet.

Fit the tin tubes end to end, and place them between the flame and the source of sound. The flame responds.

The sound waves are reflected from the inside of the tube and cannot spread; there is thus scarcely any diminution in the intensity.

Insert a funnel into the end of a long piece of india-rubber about $\frac{1}{2}''$ wide (the interior should be smooth). Place one end to the ear, and let an assistant sound a tuning-fork at the funnel end, or talk into the funnel end; the sounds are inaudible without the use of the tube.

This is the principle of speaking-tubes, speaking-trumpets, ear trumpets, and stethoscopes.

Bend the tube; it still conveys sound. When the tube is inserted into the ear and a person speaks into the funnel, an ear trumpet is formed.

If the tube were of wood, long and wider, by speaking into the mouthpiece at the narrow end, the sound waves are prevented from spreading; they leave the open end, which is directed towards the person addressed (speaking-trumpet).

18. Echoes.

Reflection of sound is the cause of echoes. In all echoes there is a reflecting surface—the walls of buildings, the sides of mountains, the trees at the edge of a forest.

The sound wave travels to the surface, is reflected, travels back to the ear. It is difficult to distinguish words that strike the ear at less intervals than $\frac{1}{10}$ of a second. To have a distinct echo the wave must travel $\frac{1100}{10}$ feet $=110$ feet; that is, the reflecting surface must be at least 55 feet away. Sometimes more than one echo is heard.

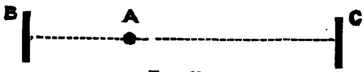


Fig. 68.

Suppose a person at A (fig. 68). A B = 110 feet, A C = 220 feet; B and C are reflecting surfaces. A pistol is red at A. The wave travels to B and back to A, and reaches the

ear in $\frac{220}{1100}=\frac{2}{10}$ second; it then travels to C, is reflected, travels back to A, and is heard $\frac{440}{1100}$ second $=\frac{4}{10}$ second later; that is, $\frac{6}{10}$ from the time of firing, $\frac{8}{10}$ second from the beginning, it will have travelled again to B and back.

But the sound wave also travels to C, is reflected, is heard at A as an echo, travels to B, is reflected, and again is heard as an echo. The times from the beginning will be $\frac{4}{10}, \frac{6}{10}, \frac{10}{10}, \frac{12}{10}$, etc., second.

B series in $\frac{2}{10}, \frac{6}{10}, \frac{8}{10}, \frac{12}{10}$, etc., second.
C series in $\frac{4}{10}, \frac{6}{10}, \frac{10}{10}, \frac{12}{10}$ " "

When more than one echo is heard from a wood it is due to the wave striking parts of the surface at various distances from the part where the echo is heard.

By using a long iron wire (200 yards at least), as in § 5, an echo can be heard reflected from the end of the wire. Attempts have been made to calculate the speed of sound in solids in this way.

In the pneumatic tubes used in the Post Office, it sometimes happens that the carrier sticks at some point. This point is discovered in this way :—

The end is covered with a thin sheet of india-rubber; a pistol is fired; the sound wave travels to the carrier, is reflected, and a flutter is seen in the membrane when it returns.

Example.—The time between firing the pistol and observing the flutter is, say, 4 seconds.

In 4 seconds, sound travels (1120×4) feet$=4480$ feet; $\therefore$ stoppage is 2240 feet from the end.

EXAMPLES. V.

1. Explain the meaning of intensity of sound; how does the intensity vary with the distance from the sonorous body? If the intensity at a distance of 100 feet be 90, what will it be at a distance of 150 feet?

2. State the conditions that affect the intensity of sound. What is a sounding-board? Why is it used?

3. How could you illustrate the reflection of sound? Describe a speaking-trumpet. Explain the principle of a speaking-tube.

4. What is an echo? An echo from a building is heard 30 seconds later than the sound; how far is the building distant?

5. A person is walking between two parallel walls which are near together, and hears a prolonged echo of each footstep; explain how the echo is produced.

6. Compare the intensities of sound at two places, one 1100 feet, the other 1800 from the origin of sound.

19. Refraction of Sound. See 'Light,' § 30.

Obtain as large a toy balloon as possible, fill it with carbonic acid gas, and suspend it from the retort ring. Place the watch two or three feet away (by trial find the best position) from the ball, and the ear on the other side of the ball close to it. The ticking of the watch is sensibly increased.

The sound waves that impinge upon the balloon are bent so that when they emerge they come to a focus close to the surface of the ball; the ear thus receives many waves that would be lost if the ball were removed.

Remove the balloon and verify this.

By inserting the end of a glass funnel into the ear and using the wide end to collect the waves, the effect is increased. Change the positions of the ear and the watch.

20. The Effect of Fog, Rain, and Wind on the Speed of Sound.

The results under this heading are due to the researches of Professor Tyndall. From experiments performed near the North Foreland he has shown that fog, which was supposed to prevent sound travelling, has scarcely any appreciable effect; the same is the case with snow and rain. The fog is accompanied by a homogeneous condition of the atmosphere that favours the passage of sound.

He found frequently on bright clear days that the atmosphere seemed to deaden sound. The report of cannon fired three miles away could not be heard. There seemed an 'acoustic cloud' between the cannon fired on a cliff and the observer, who was in a boat. The report was distinctly heard at the base of the cliff, by reflection from this invisible 'acoustic cloud.'

From researches, he concludes that these acoustic clouds are formed when the atmosphere is composed of layers of air at different densities. There is an analogy, between refraction of sound, due to this cause, and the mirage. ('Light,' § 35.)

EFFECT OF WIND.

It has been known for some time, that the speed of sound is increased or diminished, according as the wind is with or against the sound wave.

This gives no explanation why at times, when the wind is against a sound wave, the sound appears to be destroyed. The difficulty has been explained by Professor Stokes.

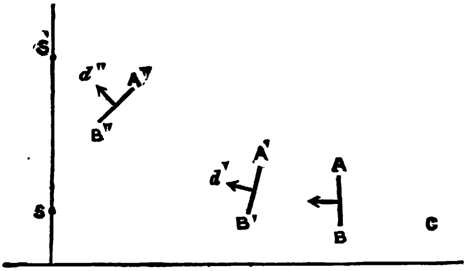


FIG. 69.

Let A B represent the front of a sound wave, the sound being produced by a sonorous body C. Let the wind oppose the sound wave; the speed will be less at B than at A, because the speed of the wind is retarded, near the surface, by the friction of the air against the earth; therefore, after a given time, A will be more retarded than B, and be in the position A′B′. The direction of a wave is at right angles to its front; the direction is changed to *d′* and afterwards to *d″*; that is, the sound wave is lifted over the head of a person at S (fig. 69).

If this be a good explanation, the spectator, by ascending a tower to S′, should then hear the sound; this is found to be the case and confirms the explanation.

Draw the figure, when the wind is in the direction of the sound wave, and show that sound waves are brought towards the earth, if the wind be in the direction of the sound.

EXAMPLES. VI.

1. On a clear day I can see the flash from a gun, but can barely hear the report. A fog spreads over; the reports can now be heard distinctly. Explain this.

2. What effect has wind upon a sound wave? The wind blows from a spectator towards a church; he is unable to hear the bells at the foot of a hill, but can hear them at the top. Why?

3. What is an echo? What is essential for the production of a single, and what of a multiple echo?

4. Describe some mode of proving that sound can be refracted like light.

5. How could you prove by experiment or observations, that, when sound is produced and heard at a distance, the air has not actually travelled to the point where the sound is heard?

6. How is it that sound is transmitted for long distances by speaking-tubes?

7. How would you show by experiment that when a bell rings, it is in motion?

8. Explain the terms speed, velocity, density, elasticity. In what respects does E in Newton's formula differ when applied to liquids and solids?

CHAPTER V.

MUSICAL SOUNDS—PITCH—INTENSITY—QUALITY.

21. PITCH.

THE experiments in the previous chapters have dealt with sounds, no particular notice being taken of the sounds called musical; the noise made by beating two stones together would have served all purposes; the sound of a cannon firing has been frequently used.

Certain sounds are pleasant to the ear; such sounds are called musical sounds.

Take the toothed wheel and fix it to the whirling table, or use the humming top (Appendix). Turn very slowly and hold a card against the teeth. At first we hear a number of taps; as the speed increases a musical noise is heard. This note continues as long as the wheel moves steadily; as the speed changes the note changes. Turn the wheel very rapidly; the sound becomes painful, and at length we are unable to detect it by the ear.

A musical note is caused by *regular vibrations*, when the vibrations are not too few (not less than 40 to the second), nor too many (20,000 to the second).

In place of the toothed wheel use the siren.

Turn and blow through a piece of bent tubing whose end is pointed over one set of holes. When the motion is very slow a series of puffs is heard. As the speed increases, a note is sounded; it increases in pitch, and at length the ear is unable to notice it.

As in last experiment, a number of regular vibrations produces a note.

Stretch a string slightly between two points and pluck it; the string vibrates: no sound is heard. Tighten it and a note is produced.

Judging from the result with Savart's wheels and the siren, the string, seeing that it gives a note, should be vibrating regularly. This will be proved presently.

Fix a knitting-needle in a vice, make it vibrate, change the length until a sound is heard; the pitch does not change as it vibrates. Does the needle vibrate a definite number of times in a second? This is best shown with a long strip of steel (use a steel straight-edge), that vibrates slower than the short needle.

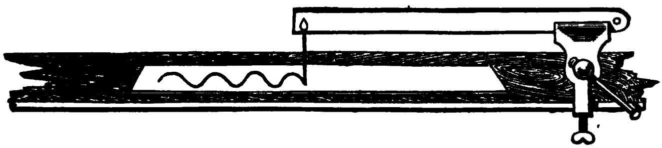


FIG. 70.

Fasten a stiff bristle to the end of the straight-edge. Smoke a long piece of glass. Arrange that the bristle touches the glass. Make the rod vibrate; it traces a line across the glass as it vibrates. Move the glass quickly.

A curve is traced; it resembles the sinuous curve in § 7, and the conclusion is that the rod vibrates with harmonic motion. If the glass could be drawn along with uniform speed, there would be the same number of waves in equal distances.

Twist a pin round the stretched cord (wire); fasten it with sealing-wax, so that the pin points horizontally; pluck the wire vertically. Draw the smoked glass rapidly past the point.

Examine the curve. Tighten the wire, and try again. The number of vibrations increases as the pitch rises.

A musical note is produced by a body vibrating a definite number of times per second.

The number of vibrations determines the *pitch of the note.*

Sound travels 1120 feet per second. If there be, say, 560 vibrations per second, the wave length for a note of that pitch is

$$\frac{1120}{560} \text{ feet} = 2 \text{ feet.}$$

THE WAVE LENGTH *determines the pitch.*

Define vibration, oscillation, wave length, period, and amplitude.

22. Musical Scale.

THE DIATONIC SCALE.

Work the siren steadily; apply the pipe to the inside circle; move it to the next circle.

Calling the first note Doh, we recognise the second as the Me of the musical scale: apply it to the third; the pitch rises and the Soh is sounded; with the outside row the Doh′, or octave, is heard.

Count the holes; they were made in the proportion 4, 5, 6, 8.

Turn the wheel at a different rate, and repeat this experiment; the same sounds are heard relative to the first.

If 400 vibrations give a certain note,
500 „ „ the third above this note,
600 „ „ „ fifth „ „ „
800 „ „ „ octave „ „ „

The musical scale consists of seven sounds; the note of lowest pitch is called the fundamental note. As in the above experiments, the relation is found between their vibration numbers. The relation is

24	27	30	32	36	40	45	48
C	D	E	F	G	A	B	C′
Doh	Ray	Me	Fah	Soh	Lah	Te	Doh′
or 1	$\frac{9}{8}$	$\frac{5}{4}$	$\frac{4}{3}$	$\frac{3}{2}$	$\frac{5}{3}$	$\frac{15}{8}$	2.

The absolute value of C is immaterial; it can be decided arbitrarily.

Seven notes, whose vibration numbers are in the above proportion, form a *natural diatonic scale.* The eighth note is called the octave to the fundamental note. The notes are named similarly above C′ and below C.

Intervals.—The interval between any two notes is expressed by the ratio of the vibration numbers.

The interval between C and D is $\frac{9}{8} \div 1 = \frac{9}{8}$
„ „ D and G is $\frac{3}{2} \div \frac{9}{8} = \frac{4}{3}$.

The intervals between each note and its predecessor by calculation are

1st	2nd	3rd	4th	5th	6th	7th	8th
	$\frac{9}{8}$,	$\frac{10}{9}$,	$\frac{16}{15}$,	$\frac{9}{8}$,	$\frac{10}{9}$,	$\frac{9}{8}$,	$\frac{16}{15}$.

The intervals $\frac{9}{8}$ and $\frac{10}{9}$ are called MAJOR and MINOR TONES.
The interval $\frac{16}{15}$ is called a SEMI-TONE.

The interval from C to D, D to E, etc., is called a second.
" " C to E, D to F " third.
" " C to G, A to E " fifth.

Between all consecutive notes, save the 3rd and 4th, 7th and 8th, another note is inserted. This note is named from the note below and is called C *sharp*, D *sharp*, etc. (written C♯, D♯), or from the note above, and is called B *flat*, A *flat*, (written B♭, A♭).

EXAMPLES. VII.

1. Explain the meaning of the terms musical interval, tone, and semitone.

2. The vibration number of a certain note is 96; find the vibration numbers of its third, fifth, and octave.

3. What are the special features of the natural diatonic scale?

4. The vibration number of a given note is 264; find the vibration numbers of the notes, that would form with it a diatonic scale.

5. If the vibration number of a note be 80, find the vibration number of the fifth above it.

23. PITCH—INTENSITY—QUALITY OR TIMBRE.

The siren, in a more expensive form, is arranged, so that the number of vibrations communicated to the air, can be exactly counted. In the whirling table used the diameter of the large wheel is 9″; of the small one 1″. One turn of the large wheel causes 9 turns of the small wheel. In the inside row there are 48 holes. Then if the large wheel turn once per second the number of vibrations $= 48 \times 9 = 432$.

When the number per second is counted it is found that notes are produced by vibrations of from 40 to 20,000 per second.

Some persons are able to detect a musical sound at 16 per

second, and others can detect notes produced by 38,000 vibrations per second.

Attach a bristle to a tuning-fork, make it vibrate and draw a smoked glass rapidly beneath it. Compare the curve with those in § 7. As the note dies away the amplitude decreases.

The INTENSITY depends upon the *square of the amplitude.*

A note of the same pitch has a different effect when produced by an organ, a fork, a string. Sounds have a certain QUALITY, depending upon the instrument producing them.

In any given medium the PITCH is proportional to the number of vibrations, i.e. to the wave length.

The INTENSITY is proportional to the square of the amplitude of the vibrating particles.

The QUALITY depends upon the particular instrument used.

24. To Find the Vibration Number of a Vibrating Body by the Sound it Produces.

To find the number of vibrations made by a whistle.

Assume that we can regulate the siren, so as to determine its speed.

Sound the whistle; turn the siren, until a note of the same pitch is heard; then from the number of holes and the number of turns calculate the number of vibrations in the siren; this equals the number made by the whistle.

EXAMPLE.

The siren sounds the note made by a whistle when it makes 10 turns per second. There are 48 holes in the siren;

$\therefore$ vibration number of siren = 480,
$\therefore$ vibration number of whistle = 480.

Tuning-forks are made to give a note of a definite pitch, and the vibration number is generally stamped upon the fork. The vibration number varies; thus the C  is frequently taken as 256; this is a convenient number. This C has been below 250, and is sometimes as high as 270; the number 264 is in common use.

Provided the C is settled, the vibration number of any other note is easily calculated.

Forks can be used for determining the vibration number.

EXAMPLE.

A whistle sounding with a fork whose vibration number is 512, gives the third above the fork (i.e. if the fork sound the Doh, the whistle sounds the Me); find the vibration number of the whistle.

The vibration numbers of Doh, Me, are as 24 : 30 or 1 : $\frac{5}{4}$,

$$\therefore 24 : 30 :: 512 : n.$$

Vibration number of whistle = 640.

EXAMPLES. VIII.

1. What are the physical differences (1) between a loud and a gentle sound, (2) between a shrill and a deep sound?

2. A bell when struck emits a note of a certain pitch. Is the wave length in air corresponding to this note the same on a warm day as on a cold day? Give full reasons for your answer.

3. Taking 1120 feet per second as the velocity of sound in air, find the number of vibrations which a middle C tuning-fork (which vibrates 264 times per second), must make before its sound is audible at a distance of 154 feet.

4. What are the three characteristics of musical sounds? How is the movement of the air particles affected by (*a*) change of pitch, (*b*) change of intensity?

5. A tuning-fork is set in vibration and you hear its note. The sound is conveyed to your ear by the motion of the air particles in the room. Explain how, and in what direction, the particles move, and state how their motion would be modified if the fork were made to give a louder sound.

6. Describe a method of determining the number of vibrations required to produce a note of given pitch.

7. When a siren makes 360 revolutions a minute, it produces the same note as an organ pipe. There are 20 holes on the wheel. Find the vibration number of the pipe.

CHAPTER VI.

VIBRATIONS OF STRINGS AND RODS.

25. Transverse Vibrations of Strings.

FASTEN one end of an india-rubber tube, 12 feet long, filled with sand, to the ceiling. The sand makes the movements slower. Hold the other end in the hand; stretch slightly and give a jerk to the right, and bring the hand back to its first position: a crest travels along the tube (fig. 71). The two figures give the positions at two different times.

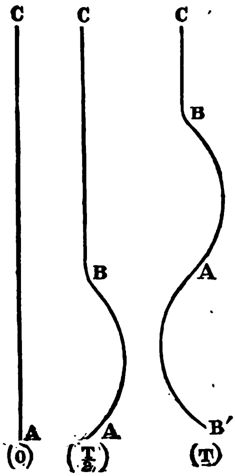


Fig. 71.

STATIONARY PULSES.

By timing the hand properly, the hillock can be made to take up the whole length of the tube.

At the end the hillock is reflected. By giving a series of similar jerks this motion will be repeated, and the string as a whole swings from side to side. It forms *a stationary pulse.* Compare this with the crest of a wave *moving along the tube*, as in fig. 71.

Give two jerks in the same time as one was given in the last experiment. The hillock takes the position *a*, then *b* (fig. 72, A, B). At the fixed end it is reflected as *c*, and would return to the hand as *d c*; just when the reflection takes place at *c*, give another jerk. Then *e* appears, and reaches *n* just as *c* reaches *n*. *e* would move

n to the right, *c* would move it to the left; both forces being equal *n* remains fixed. *e* is reflected as *d* from the fixed point *n*; *c* is re-

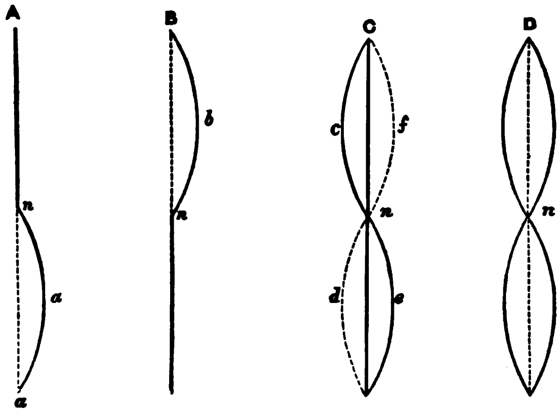


FIG. 72.

flected as *f* from the fixed point *n*. If the jerks continue the tube vibrates as in D—that is, *two stationary pulses* are produced.

By increasing the rates at which the jerks are given, the tube can be broken up into 3, 4, 5, or any number of stationary pulses.

Having discovered, by experiment, the rate at which the jerks must be given, to cause the string to vibrate as a whole, make the jerks as small as possible; at first the amplitude is so small, that the movement of the tube can scarcely be recognised. Continue the jerks; the amplitude gradually increases.

By a series of very small jerks with the hand, a marked movement is produced in the string.

Several instances can be cited, of small impulses given regularly producing such results. Suspend a weight by a string; give it a very slight push, and repeat this push as it swings back to the hand; the amplitude increases. A large ship, when subjected to a regular series of small waves, begins to rock in a way that ultimately may become dangerous. A water-carrier sets the water in his pails in motion by the swing of his body: the motion at first is only slight; each swing

of the body increases the motion, and the water would soon overflow if he did not alter his step.

In fig. 72, *n* is not really at rest; if it be clamped so as to be rigid, no motion would appear at *c* or *f*. *n* makes a number of *very small* movements; these set the part *c f* vibrating. That is, *c f* vibrates as if a hand were at *n*.

Stretch the tube horizontally between two points A,B; pluck it in the middle: it vibrates as a whole (fig. 73).

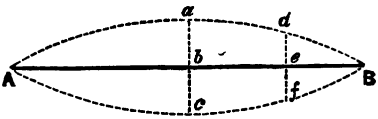


FIG. 73.

Consider a portion of the tube *e*; its transverse motion is harmonic.

Test this by attaching a stile to *e*, and drawing a piece of smoked glass rapidly beneath it as it vibrates as on p. 132. The curve of § 7 is produced.

The period is evidently the time in moving from *e* to *d*, from *d* to *f*, and back from *f* to *e*.

From A to B is only half a wave length.

When a string vibrates as a whole, its length is one-half of the wave length.

A point of apparent rest *n* (fig. 72) is called a NODE.

The vibrating part (A *a d* B) is called a VENTRAL SEGMENT.

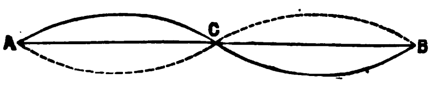


FIG. 74.

Touch the tube with the finger at its centre C; pluck CB in the middle (fig. 74); the tube breaks up into two ventral segments.

A C vibrates because C is not absolutely at rest; it makes a number of small movements (jerks); these are of the time to make A C vibrate.

Touch the tube at one-third of its length from B. Pluck between D and B (fig. 75).

FIG. 75.

D B vibrates as a ventral segment. D is a node and A D breaks into two ventral segments. The movement of D (node) is timed so as to set E D vibrating; E moves so as to set A E vibrating.

In fig. 74 A B forms a complete wave; in fig. 75 A D or E B forms a complete wave.

26. LAWS OF THE TRANSVERSE VIBRATIONS OF STRINGS.

Stretch a wire on the sonometer; pluck it in the middle: it vibrates as one ventral segment. A note is produced (increase the weight if necessary).

The note sounded by a stretched string or wire, vibrating as a whole, is called the fundamental note, for that length of wire.

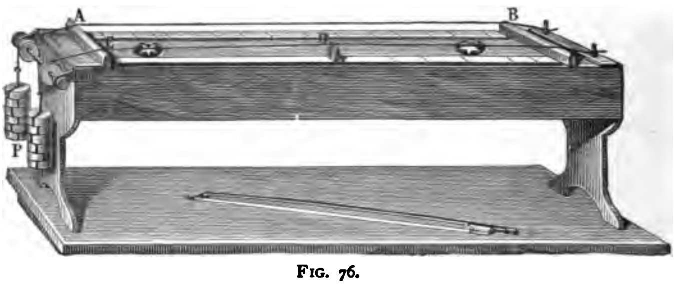


FIG. 76.

Touch the wire in the middle, and pluck it at $\frac{1}{4}$ of its length from one end. It vibrates as two ventral segments, and the octave to the fundamental is heard.

The vibration number of the octave is twice that of the fundamental. This agrees with the experiment with the tube (§ 25). By doubling the number of jerks, we divided the tube into two ventral segments.

Damp the wire at $\frac{1}{3}$ its distance from one end; bow it with a violin bow $\frac{1}{6}$ from same end: 3 ventral segments are produced; the 5th above the last octave—that is, the 12th above the fundamental note—is heard.

Length	Sound	Vibration No.
1	fundamental	1
$\frac{1}{2}$	octave	2
$\frac{1}{3}$	twelfth	3

FIRST LAW.—*The number of vibrations per second is inversely as the length of the string.*

TO VERIFY THIS LAW.

What should be the lengths of two strings to produce the sounds Doh and Soh respectively—that is, the second note, is to be the 5th above the first?

The vibration numbers are as 24 : 36,

$\therefore$ lengths should be as 3 : 2.

Stretch two similar wires, so that they sound the same note. Place the movable bridges so that the distance from pulley to bridge in the two wires is as 3 : 2. Bow these parts; the Doh and Soh are heard.

The position of nodes and loops (the widest part of the ventral segment) is easily shown by placing small paper riders (Λ) astride the string or wire at various parts. The riders remain on the nodes and are jerked off the loops.

MONOCHORD.

If the law hold good, by using one wire of definite length, and dividing the length successively in the ratios

$$1, \frac{8}{9}, \frac{4}{5}, \frac{3}{4}, \frac{2}{3}, \frac{3}{5}, \frac{8}{15}, \frac{1}{2},$$

the notes of the diatonic scale should be produced.

By using the distance 1, the fundamental should be heard.
" " $\frac{8}{9}$ the 2nd above the fundamental should be heard
" " $\frac{2}{3}$ the fifth
" " $\frac{1}{2}$ the octave
etc. Try this.

A string so divided and mounted on a box is called a MONOCHORD.

LAW OF STRETCHING WEIGHT.

Keep the lengths the same; vary the stretching weight. Hang a weight of 16 lbs. to each of two similar wires; increase the weight on one wire until the third is heard, the fifth, and the octave (or any other note of the scale). Note the weights.

Stretching weight	Sound	Vibration No.
16	Doh	1 4
25	Me	$\frac{5}{4}$ or 5
36	Soh	$\frac{3}{2}$ 6
64	Doh′	2 8

The square root of each number in column 1 gives the last number in column 3.

SECOND LAW.—*The vibration number (other things being equal) is directly proportional to the square root of the stretching force.*

EXAMPLE.

A string stretched by a weight of 4 lbs. sounds a certain note (Doh); what weight will be needed to sound the Fah (4th) of the scale?

$$\frac{\text{Vibration No. of the Doh}}{\text{,, \quad ,, \quad ,, \quad Fah}} = \frac{\sqrt{4}}{\sqrt{W}}$$

$$\frac{1}{\frac{4}{3}} = \frac{2}{\sqrt{W}} \therefore 3\sqrt{W} = 8$$

$$\therefore W = 7\tfrac{1}{9} \text{ lbs.} \qquad \text{Test this.}$$

The THIRD LAW refers to the diameters of strings.

It is not easy to measure the diameters directly.

A string is a long cylinder: if r be the radius, l the length, d the density;

The volume $= \pi r^2 l$. The mass $= \pi r^2 l d$.

To compare the diameter of two strings, take equal lengths and obtain

the masses by weighing. Let M be the mass of the first, M_1 of the second, r and r_1 the radii.

$$\text{Then } \frac{M}{M_1} = \frac{\pi r^2 ld}{\pi r_1^2 ld} = \frac{r^2}{r_1^2} \therefore \frac{r}{r_1} = \sqrt{\frac{M}{M_1}}$$

That is, the radii are proportional to the square roots of the masses.

By this method obtain the relative radii, and therefore the relative diameters of two strings. Suppose these relations to be 6 : 4; use the same stretching weight, the same length; the thicker string gives the note of lower pitch; by shortening the thicker string bring the two notes into unison; compare the lengths. Thick string = 4 units. Thin string = 6 units; that is, the diameters or radii are inversely as the lengths of the strings. The number of vibrations are equal.

If the thick string be now lengthened to 6 units; by the first law, it will give $\frac{4}{6}$ the number of vibrations it gives when the length is 4, that is, $\frac{4}{6}$ time the number of vibrations of the thin string under like conditions; or when the diameters are as 4 : 6 the vibration numbers are as 6 : 4.

THIRD LAW.—*The number of vibrations per second is inversely as the diameters of the string.*

The FOURTH LAW refers to the density of the strings.

If a catgut string and a copper wire (length, diameter, and stretching force the same in both cases) be used on the sonometer, the copper wire gives the lower note. This is why the fourth string of a violin, and the lower wires of a piano, are wrapped round with wire. The density is increased.

FOURTH LAW.—*The vibration numbers are inversely proportional to the square roots of the densities.*

27. FORMULA FOR THE TRANSVERSE VIBRATIONS OF STRINGS.

[The laws for the transverse vibrations of strings can be expressed in one formula. If l = length of string, r = radius, P = mass of stretching weight (Pg = stretching force), d = density, n = vibration number,

$$n = \frac{1}{2rl}\sqrt{\frac{Pg}{\pi d}}$$

This can be written $\frac{1}{2l}\sqrt{\frac{Pg}{\pi r^2 d}}$.

$\pi r^2 d$ = mass of unit length

Pg = stretching force or tension (T).

$\therefore n = \frac{1}{2l}\sqrt{\frac{T}{m}}$.]

The vibration number varies inversely as the length; inversely as the square root of mass of unit length; directly as the square root of the tension.

—	Stretching forces	Densities	Lengths	Radii or diameters	The vibration numbers vary
If in 2 strings	×	×	o	×	Inversely as the lengths
,, ,,	×	×	×	o	Inversely as the radii or diameters
,, ,,	×	o	×	×	Inversely as the square roots of the densities
,, ,,	o	×	×	×	Directly as the square roots of the stretching forces

For × read 'are equal;' for o read 'vary.'

EXAMPLES. IX.

1. Explain the terms node, ventral segment, wave length, amplitude, period.

2. A stretched string 10 feet long is, in unison with a tuning-fork, marked 256; the string is shortened 4 feet: how often will it now vibrate in a second?

3. Describe experiments which illustrate the laws of transverse vibrations of stretched strings.

4. A string is fastened at one end to a peg in a horizontal board, and the other end passes over a pulley and carries sixteen pounds. The string gives the note C. What weight must be hung instead of the sixteen pounds, so that the string gives the next lowest octave?

5. Two equally stretched strings of the same thickness, one of steel and the other of catgut, give the same note when struck. Which of them is the longer? Give reasons for your answer.

6. Four strings of the same length and material, but of different thicknesses, are stretched on a violin, and tuned so as to give successive fifths. If the tension be the same, compare the thickness of the strings.

7. In the last question, what must be the tension on the several strings, that they may all give the same note?

8. Explain what law must hold between the length and area of the section of strings, in order that, under the same tension, they may vibrate at the same rate. Describe an experiment which illustrates this law.

9. Describe how you would employ the monochord, to show the relation between the tension of a string, and the pitch of the note given by it.

10. Explain how to construct an instrument with strings of the same material and thickness, so that, under the same tension, the successive strings may give the consecutive notes of the major scale.

11. Given two strings of the same thickness, one of steel and the other of catgut. One end of each is fastened to a peg in a horizontal board, and the other end passes over a pulley and is stretched by a weight. The distance between the peg and the pulley is the same for both, and the stretching weights are equal. Which string gives the higher note, and why? If you wished, by altering the weights, to make both notes of the same pitch, how would you do it?

28. Harmonics—Quality or Timbre.

Pluck a long stretched wire (10 or 12 feet) near one end; as it vibrates touch it in the middle lightly; it is now unable to vibrate as a whole.

On placing the ear near the wire the octave is heard; the wire is vibrating in halves (fig. 77, A). Experienced ears can detect the octave while the fundamental note is sounding.

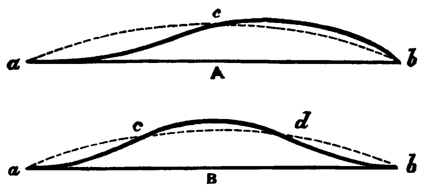


FIG. 77.

The wire may be represented swinging, as in fig. 77, A; on damping in *c*, the segments *a c*, *c b* alone vibrate.

The wire may also divide into three portions, a note having

three times the number of vibrations of the fundamental being produced at the same time as the fundamental (fig. 77, B).

These other sounds produced are called HARMONICS or OVERTONES.

In strings their vibration numbers, compared with the fundamental as 1, are as 2, 3, 4, 5, 6, etc.; i.e. octave, 12th, double octave, etc.

In fig. 77, the amplitude is greatly exaggerated.

The vibrations of the segments, are taking place at the same time as the string vibrates as a whole.

The overtones, combined with the fundamental, give the QUALITY *of the note, or the* TIMBRE.

If we wish to produce the 12th say, we must avoid plucking at any point (see fig. 77, B) where a node of the 12th would come; the best place will be a ventral segment, that is $\frac{1}{6}$ from one end, or in the middle.

Piano-strings are struck by the hammer, between $\frac{1}{7}$ and $\frac{1}{9}$ from one end, thus avoiding any point that would interfere with the production of the first set of overtones.

The piercing *quality* of sounds is generally due to the presence of high harmonics.

EXAMPLES. X.

1. What are harmonics, or overtones? how can you show their presence by using a stretched wire?

2. Explain 'quality' as applied to musical sounds.

3. What is the reason that the hammers which strike the strings of a piano-forte are made not to strike the middle of the strings? Why are the bass strings loaded with coils of wire?

4. Explain how the pitch of a note given by a string vibrating transversely depends upon its length, size, and tension. State the effect which is produced, by touching, for an instant, a point of a vibrating string. How ought this to influence a violin player, as to the position where he should bow the string?

5. How would you prove experimentally, that the tone of a stretched string vibrating transversely, is compound in its nature? If you wish to express the second harmonic, the twelfth above the fundamental, where would you pluck or strike the string?

6. In what respects is it possible for two musical notes to differ from each other, and on what physical causes do the differences depend?

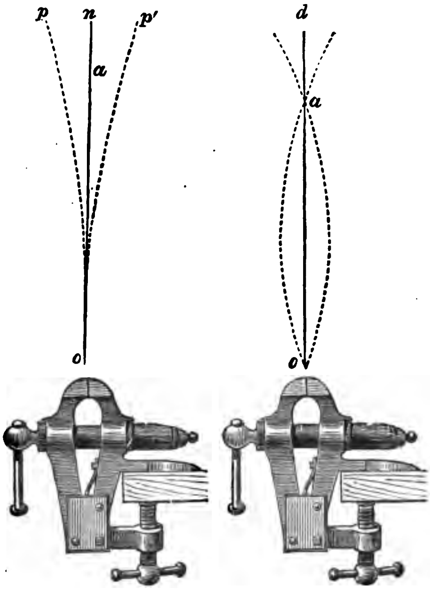
29. Transverse Vibration of Rods.

Clamp a knitting-needle in a vice and pluck its point; it vibrates; if the vibrations be rapid enough a tone will be produced (fig. 78). Shorten it and produce a sound.

By using the style and smoked glass examine the motion.

The length of the rod is $\frac{1}{4}$ of a wave length. Shorten the rod; the pitch rises. The vibration number is inversely as the *square of the length.* If the lengths be as 1, $\frac{1}{2}$, $\frac{1}{3}$, $\frac{2}{7}$, etc., the vibration numbers will be as 1, 4, 9, $\frac{49}{4}$, etc.

Musical boxes are composed of rods, fixed at one end; the small projections in the barrel set the tongues vibrating.



A FIG. 78. B

If the rod divide into segments, while producing the fundamental, so that the first harmonic or overtone is also produced, the tip must always be a loop and the fixed end a node. The first possible division is as in figure B. The vibration number of the first overtone thus produced, is

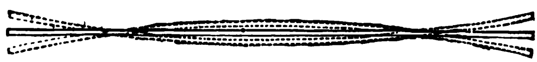


FIG. 79.

to that of the fundamental as 5^2 is to 2^2. The rates of the overtones from the first, are as the *squares* of 3, 5, 7, etc.

If a rod be free at both ends, its fundamental note is produced by clamping it at a point between $\frac{1}{4}$ and $\frac{1}{5}$ of its length from the end.

FIG. 80.

Support a strip of glass on two rests, each $\frac{1}{4}$ of the length of the strip from each end; tap it with a penholder; its fundamental note is heard (fig. 79).

Several such glasses, properly cut, form the glass harmonicon (fig. 80).

30. TUNING-FORK.

When a rod, free at both ends, is bent, the nodes approach each other. This is the case in the tuning-fork, where the nodes are near the root. The fork vibrates, as in fig. 81, and thus the handle is moved up and down and communicates its motion to a sounding-board.

FIG. 81.

Clamp the tuning-fork, so that the prongs are horizontal; sprinkle sand upon it, bow it, and find the position of the nodal lines.

The tuning-fork is remarkably free from harmonics, that affect the quality of its sound.

EXAMPLES. XI.

1. A knitting-needle, 6 inches long, vibrates 30 times in a second; it is divided into two equal parts. How often will each part vibrate per second?

2. The fundamental note of a rod fixed at one end is C; what is the first harmonic? How are their vibration numbers related?

3. Describe the tuning-fork. How would you show the presence of nodes?

4. State the laws of the transverse vibrations of rods fixed at one end. What relation holds between the number of vibrations for the successive overtones in such rods?

CHAPTER VII.

VIBRATION OF AIR IN TUBES—LONGITUDINAL VIBRATION OF RODS.

31. Open and Stopped Pipes.

In previous experiments sound has been produced by solid bodies. Gases are capable of being thrown into vibration and producing sounds when they are confined in tubes.

The music of Pan's pipes, the note produced by blowing across a key, are examples of such sounds. The straw and the key take no part in the vibration, as the sound does not depend upon the material of which the tube is composed, and the sound is not changed or prevented by touching the tube at any point.

Make 4 cardboard tubes 1″ diameter, 16″, 12″, 10″, and 8″ long. Cover one end by gluing on circles of cardboard. Resting the closed ends on the table, allow them to fall one after the other; the four notes Doh, Me, Soh, Doh′, due to the air in the tubes vibrating, will be distinguished.

The vibration numbers of these sounds are as $4 : 5 : 6 : 8$; the lengths of the pipes are as $8 : 6 : 5 : 4$.

Take a glass tube; close one end with the finger (a stopped pipe) and blow across the other end; remove the finger (open pipe), again blow; the octave is heard. Repeat this with tubes of various lengths.

The sound produced by the air in a stopped tube is an octave lower than the sound produced by the air in an open tube.

32. How the Air Vibrates in Pipes.

The distinction between a *progressive sound wave* and a *stationary wave* must be clearly understood. In a progressive

wave each successive particle moves from its position of rest a little later than the preceding one (§ 7). In each half of a stationary wave (a pulse), every particle begins to move at the same time.

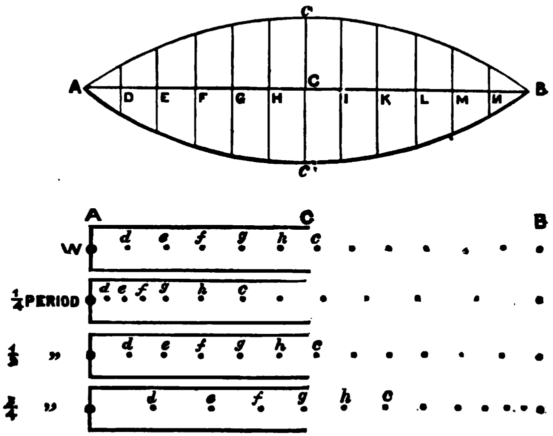


FIG. 82.

Imagine AB (fig. 82), a stationary pulse caused by particles vibrating transversely (across the direction of the wave). Divide the distance AB into 12 or any number of parts; draw transverse lines; each particle D, E, F, etc., moves with harmonic motion, ***but all begin moving at the same time and move always in the same direction.*** The amplitude is o at the nodes, and is greatest at the ventral segment.

In $\frac{1}{4}$ period the position is A*c*B
" $\frac{1}{2}$ " " " " ACB
" $\frac{3}{4}$ " " " " A*c'*B
" $\frac{4}{4}$ " " " " ACB

In sound waves the particles move with harmonic motion, but the particles move ***in the line of direction*** of the wave, and again the amplitude is less as the particles are near the nodes.

33. Longitudinal Vibrations of Air Particles—Stationary Sound Waves.

Imagine, then, that each line, D, E, F, etc., be twisted in the direction of the hands of a watch, on D, E, F, etc., as centres, so as to lie along A B, and that the particles vibrate as before along *c* C *c*′, *h* H *h*′, vibrating longitudinally instead of transversely.

The position of the particles at each quarter-period is shown, in the four lower diagrams of fig. 82; all the particles in a half wave-length, move in the same direction at the same time and for the same time, their amplitudes increasing from the nodes. It is seen that A and B (nodes) do not move, also that the greatest rarefaction and the greatest compression take place at A and B. The least rarefaction and least compression are at the ventral segment.

The stationary sound wave may also be studied by the aid of fig. 83.

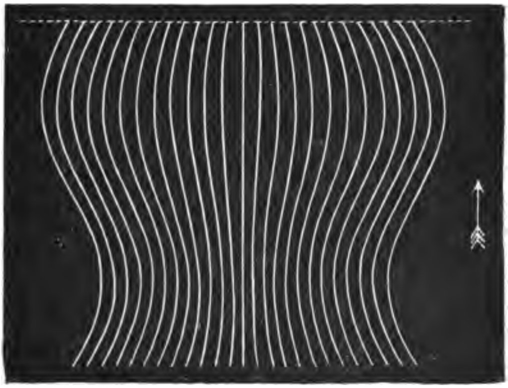


Fig. 83.

Place a slit (fig. 64) on the dotted line of fig. 83, and draw the book beneath the slit in the direction of the arrow. The dots seen form the half of a stationary wave.

The central line (straight) represents a node, the outside curves the ventral segments. The curves inform us that the amplitude is smallest at the nodes.

Suppose you have a stopped tube giving its fundamental note; then the mouth must be a ventral segment, and the bottom a node. The tube is shown in outline, fig. 82. The bottom is represented by A, the mouth by C, and the depth of the tube is $\frac{1}{4}$ the wave length (A B is one half wave-length).

The motion of the particles can be studied by examining the position of the dots from *d* to *c* at each quarter-period; compare their positions with the quarter-periods, when the vibration is transversal.

It is in this manner that the air particles move in a stopped tube, when the fundamental note is sounding. The particles would of course be infinitely nearer to each other; a large number instead of one would occupy any section of the tube, and the amplitudes would be very small.

Insert a cork loosely in a glass tube; arrange so that the cork is 12″ from one end; blow gently across the mouth and note the sound. Call it Doh. Push the cork until, on blowing, the third (Me) is heard; measure the distance from cork to mouth: proceed similarly for Soh and Doh′.

Note	Vibration No. of stopped pipe	Length of tube	Vibration No. of open pipe
Doh (1)	4	12	8
Me ($\frac{5}{4}$)	5	9	10
Soh ($\frac{3}{2}$)	6	$7\frac{1}{2}$	12
Doh′(2)	8	6	16

$$12 : 9 :: 7\tfrac{1}{2} :: 6 = 8 : 6 : 5 : 4.$$

In stopped pipes the number of vibrations per second is inversely as the length of the tube.

Remember, that the ratio of the vibration numbers (column 2) has been determined by the siren and Savart's wheel.

An open pipe yields a note with twice the number of vibrations per second, that the stopped pipe yields (§ 31). The number of vibrations for the open pipe (column 4) is thus obtained at once. In the above table these numbers are as 4 : 5 : 6 : 8.

Therefore, in an open or in a stopped pipe, the number of vibrations per second is inversely as the length of the tube.

In blowing across a tube it is not always easy to obtain a good musical sound; the relation between the notes is, however, easily perceived.

34. Overtones in Open and Stopped Pipes.

Blow strongly across a closed tube; another note much higher than the fundamental note can be heard; this is the first overtone; it is the 12th above the fundamental. Remember, the overtone was sounding before, but we could not detect it.

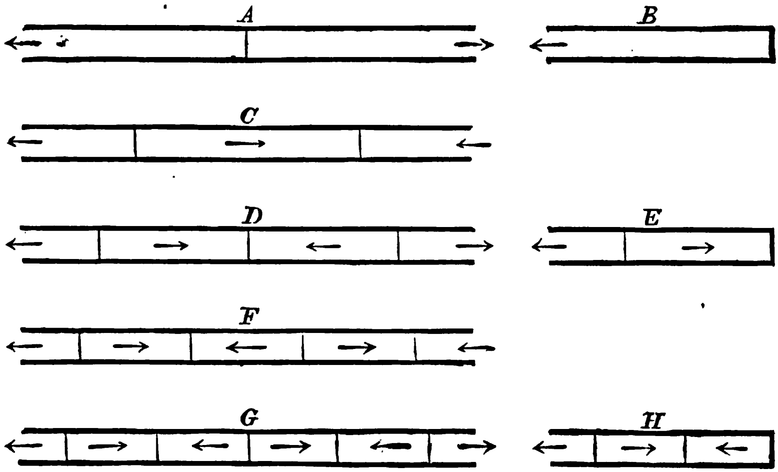


Fig. 84.

B, fig. 84, represents the tube giving the fundamental; the particles of air move towards the bottom and back. In E the first overtone is produced; the node is marked by the line. The particles will be alternately moving to and away from the node. (Draw the tube with the arrow-heads reversed.) H represents the nodes when the next overtone is produced. The lengths of the quarter-waves, and therefore of the whole waves, are as 1 : 3 : 5 : 7, etc.

These represent the ratio of the vibration numbers of the fundamental and the overtones.

An open pipe gives a note an octave higher than a closed pipe of the same length; it gives the same note as a closed pipe one half its length. It is, in fact, unimportant for the fundamental note, whether A, D, and G are formed each by single pipe open at each end, or of two equal closed pipes, the closed ends being in contact. (Examine the figures.)

In addition to the nodes in A, D, and G obtained by joining two closed pipes, the air can vibrate in an open pipe, as in C (this is the first overtone of an open pipe), and as in F.

One-quarter wave-lengths (∴ whole wave-lengths) of the fundamental and overtones are in open pipes as 1 : 2 : 3 : 4 : 5, etc. These give the ratio of the vibration numbers of the fundamental and the overtones or harmonics in open pipes. By blowing with sufficient force, these overtones can be heard.

The combination of overtones with the fundamental, gives the quality of the sound in any instrument.

35. Production of Sound in Tubes.

Resonance.

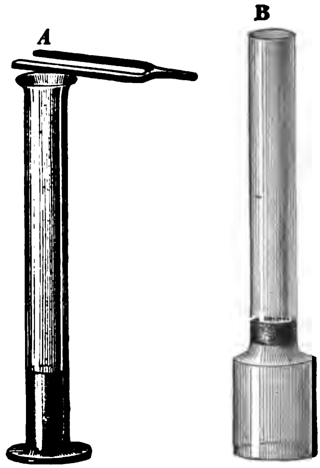


Fig. 85.

Take a tuning-fork of low pitch, hold it in the hand, and cause it to vibrate. Hold it over a tall jar about 18″ long (fig. 85, A). Pour water into the jar; at a certain height the note suddenly becomes reinforced. Measure from the mouth to the water; pour more water in; the sound disappears. This strengthening of the sound is called RESONANCE. By pushing a cork up a glass tube (a lamp glass) the same results are obtained (fig. 85, B). Try another fork, G; again obtain the required depth; remove the tuning-fork and blow across the mouth; the same note is heard as that produced by the fork.

Resonance in a stopped tube is possible, when the air can

be set in vibration, so as to produce the same sound as the sonorous body produces.

Measure the depth of the tube in a few experiments.

Name of fork	Vibration No.	Length of sound wave (calculated)	Depth of tube (measured)
C	256	$\frac{1120}{256}$ ft. = 52 inches	13
G	324	$\frac{1120}{324}$ „ = 35 „	$8\frac{3}{4}$
C	512	$\frac{1120}{512}$ „ = 26 „	$6\frac{1}{2}$

The depth of the resonant tube is one quarter the wave length; this agrees with the conclusion in section 33.

Cut a number of tubes the required length; glue circles of cardboard to one end. These form resonators.

If resonating tubes open at both ends be used, they will be one half the length of the open tubes.

Take two tuning-forks in unison; sound one; stop it. The other fork is found to be vibrating. Sing a clear note near a piano; a certain wire will respond to the note. It is the same wire that, when struck, produces the note.

36. To Make a Resonant Box for a Tuning-Fork.

The box should be made of thin wood and be about 3″ wide, $1\frac{1}{2}$″ deep. Glue the sides together. Glue a reel on to the top; insert the tuning-fork in the hole of the reel. The box should rest on short lengths of india-rubber tubing.

Calculate roughly the lengths of the boxes thus:

$$\text{length in inches} = \frac{1120 \times 12}{\text{vibration No.}} \div 4.$$

Test with fork and tube before finishing.

The vibrations are communicated to the top; this, being thin, vibrates; the column of air takes up the vibrations.

It should be remembered that in all cases of resonance, while the note is reinforced, it sounds for a shorter time.

If it be required to keep the tuning-fork vibrating a long time hold it in the hand; the sound is feeble. Place it on the resonator; the sound is full, but it soon ceases.

EXAMPLES. XII.

1. What is meant by a stationary wave? Compare it with a progressive wave.

2. Calculate the depth of a resonant jar for a fork marked 256. What is the length of the sound wave?

3. How do the harmonics affect the sound produced by a tube?

4. If you blow across the open end of a key, you can frequently obtain a shrill note. What connection is there between the length of the key and the shrillness of the note?

5. A tuning-fork, making 384 vibrations per second, is held over a cylindrical jar filled with air, in which the velocity of sound is 1100 feet per second. What must be the length of the jar in order that it may be best adapted to resound to the fork? What is the length of the wave sent out by the fork?

6. When a tuning-fork is set in vibration, and held close to one end of a glass tube 20 inches long and open at both ends, an augmentation of sound takes place. If the tube be longer or shorter than 20 inches, the increase of sound is not so great. How do you explain these facts? and how could you calculate from them the pitch of the tuning-fork?

7. A tuning-fork C gives 256 vibrations a second; it is held over the open end of a pipe closed at one end, which gives the same fundamental tone as the fork. Explain the change of state of the air in the pipe during the complete vibration of the fork.

8. Explain how to determine the time of vibration of a given tuning-fork, and state what apparatus you would require for the purpose.

9. A stopped pipe 2 feet long and an open pipe 4 feet long give the same fundamental notes. How do these two notes differ in quality? What determines the quality or timbre of a note?

37. REEDS.

A column of air can be set vibrating by the vibrations of an elastic plate, as in the case of the clarionet. The simplest form is the pipe made of straw.

FIG. 86.

A straw is cut off above a knot; this gives the closed end. The straw is slit upwards by a sharp knife for about one inch. The slit part is placed in the mouth and by blowing *r r* vibrates; *r r* can vibrate at different rates, but one note is characteristic of the pipe.

The length *r s* determines this note; *r r* vibrates so that the note it produces is reinforced by the air vibrating in *r s*.

r r is an example of a BEATING REED. If the tongue *r r* could pass through the slit, into the pipe, it would be termed a FREE REED.

38. ORGAN PIPES.

The construction of organ pipes will be understood from fig. 87. Air enters at P, and emerges at *i*; the current

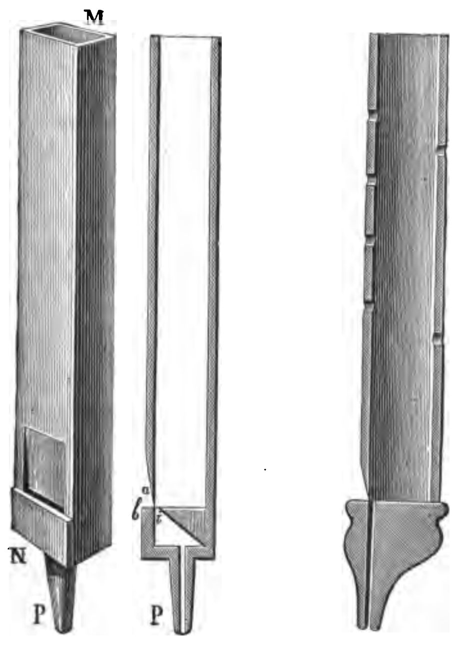


FIG. 87.

strikes against the lip *a*; the air is compressed, forces *a* outwards, and escapes; *a* by its elasticity springs back; this is repeated, a series of puffs escapes, and exactly as in the siren a note is produced. The length of the pipe is so arranged that it acts as a resonant tube to these pulsations. Its length

can be determined by what has been said of closed and open pipes.

The overtones follow the same laws as the simple pipes.

Fig. 87, F, is the section of a flageolet ; omitting the holes on the under side, it is the ordinary whistle. When the holes are closed, the whole of the air in the whistle vibrates. If a finger be lifted, the hole determines the position of a ventral segment, and therefore the pitch of the note.

39. To Measure the Speed of Sound in Gases by Using Pipes.

With a tuning-fork A, vibration number 440, find the velocity of sound in air, and in coal gas.

By means of a jar find the length of a closed resonant tube (§ 35).

$$\text{This length} = 7{\cdot}6 \text{ inches},$$
$$\therefore 7{\cdot}6 \text{ is } \tfrac{1}{4} \text{ wave length},$$
$$\therefore 1 \text{ wave length} = 30{\cdot}4 \text{ inches}.$$

440 of these vibrations occur in one second.

$\therefore$ $30{\cdot}4 \times 440$ inches $=$ speed of sound in air $= 1114{\cdot}7$ feet. Verify by using an open tube.

Fill the tube with coal gas. Hold the tube mouth downwards over a gas jet ; push the cork, until the tube acts as a resonant tube to the fork. A closed tube filled with coal gas reinforces the note at a depth of $10{\cdot}5$ ins. ;

$$\therefore \text{length of wave in coal gas} = 42 \text{ ins.} ;$$
$$\therefore \text{speed of sound in coal gas} = 42 \text{ ins.} \times 440 = 1457 \text{ ft.}$$

Repeat the same experiments with hydrogen gas, and carbonic acid gas, as with coal gas.

40. To Show the Presence of Nodes and Loops in Pipes.

(1) A child's wooden whistle is cut off just behind the first finger-hole and fastened into a glass tube three times its length ; the end is closed with a cork, and fine sand is sifted into the tube. When the fundamental note is sounded, the dust is set in motion and accumulates at the nodes (fig. 88).

(2) Make a small tambourine by covering a circle of wire 1″ radius tightly with tissue paper; when an organ pipe with a

FIG. 88.

glass front is sounding, lower the tambourine, on which sand is sprinkled; the fluttering of the paper and the movement of the sand indicate the position of the loops (fig. 89).

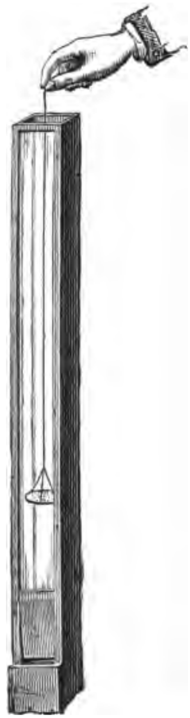


FIG. 89.

EXAMPLES. XIII.

1. Explain the way in which the air vibrates in an open organ pipe sounding its fundamental note. How would you show the state of motion of the air?

2. In the case of an open organ pipe which is sounding its fundamental note, state clearly (1) in what manner and direction the air particles are moving; (2) how the wave in the pipe is produced.

3. By what means would you test the state of disturbance of the air at any part of an open organ pipe, when a musical note is being produced in it? What is the state of the air in the pipe when the first harmonic is being produced in it?

4. A stopped organ pipe 4 feet long, and an open organ pipe 12 feet long, are sounded. How are the notes related to each other? Do they differ from each other in quality, and, if so, why?

5. Assuming the velocity of sound in air to be 1120 feet per second, determine the length of the wave produced in air by a tuning-fork vibrating 384 times per second. Determine also the length of an open organ pipe which would yield the same note as the tuning-fork.

6. Explain how to divide an open organ pipe into two parts, so that, both being open organ pipes, the note given by one of the parts, is the octave of the note given by the other. How are these notes related to the fundamental of the whole pipe?

7. Describe a method of testing the state of the air at any part of an

open organ pipe when a musical note is being produced from it. What result will be obtained by the test, when the first harmonic is being produced from the pipe?

8. What is the relation between the wave length in air of a note, and the length of the closed organ pipe which resounds to it? Account for the difference in the quality of notes of the same pitch, from a closed, and open organ pipe.

41. Longitudinal Vibration of Rods.

Fixed at both Ends.

Draw the violin bow along the string of the sonometer, or rub it in the direction of its length.

The sounds are produced by the particles vibrating in the direction of the length of the rod, and forming stationary waves, as they did in the case of the vibrating columns of air in pipes.

These experiments should be performed with a wire or rod as long as possible. In the fundamental note, if both ends be fixed, the particles move first in the direction of one end, then in the direction of the other, forming the half of a stationary wave. (Consider the whole of the particles in fig. 82 in the four periods.) Damp the rod in the centre; the octave is heard and C becomes a node. All the particles move towards C, then away from C. The number of vibrations is inversely as the length of the rod. The vibration numbers of the fundamental note and the harmonics are as 1, 2, 3, 4, 5. If the rod be rubbed at any point, a node cannot form there; thus certain harmonics will be suppressed.

Fixed at One End.

Clamp a rod at one end, and cause it to vibrate longitudinally, by drawing a rosined cloth along it; the clamped end is a node, the free end the middle of the ventral segment.

How do the particles vibrate? A small glass bead placed opposite the free end is forced away by the vibrations. The rod is like a stopped pipe giving the fundamental, and the wave length in the material is four times the length of the rod. As the rod is shortened the pitch rises. By taking half the length the octave is heard; one-third the length, the 12th.

The vibration number is inversely as the length of the rod.

The vibration numbers of the fundamental, and the harmonics or overtones, as in stopped pipes, will be as 1, 3, 5, 7, etc.

The stopped pipes were used to determine the speed of sound, in the gas filling the pipes. Try this with the rods.

Clamp a rod of oak 7 feet in length at one end; draw the resined glove along it until a note is heard; shorten it until it agrees with the tuning-fork whose vibration number is known; aid this sound with a proper resonant jar.

Suppose the fork to be marked, 512; the rod to be 6 feet 3 inches,

$$\therefore \text{ 1 wave length} = 25 \text{ feet.}$$

Wave length × number of vibrations per second = speed;

$25 \times 512 = 12800$ feet per second=speed of sound in oak.

Or suppose we arranged that a resonant jar gave the note produced by the oak, and we measured the depth of the jar (6·6 inches):

$$\frac{\text{wave length in air}}{\text{" \quad " \quad oak}} = \frac{4 \times 6{\cdot}6 \text{ ins.}}{4 \times 6 \text{ feet 3 inches}} = \frac{22}{250} = \frac{88}{1000}$$
$$= \frac{\text{speed in air}}{\text{" \quad oak}}$$

speed in air = 1120 feet per second.

$\therefore$ " " oak = 12,728 " "

By using different woods or metals, and by cutting them down to give the same note, the speeds can be compared.

Fixed in the Middle.

Clamp the long glass rod in the middle and excite it longitudinally; a pure sound is heard. The middle is a node, the end a ventral segment.

The pitch is inversely as the length of the tube; the tube is like an open pipe.

The vibration numbers of the fundamental and the harmonics will be as 1, 2, 3, 4, 5, etc.

Arrange a resonant jar to sound C (512 vibrations); clamp a rod of beech 10 feet long in the middle, and make it vibrate longitudinally; shorten the rod until it is in unison with the jar

The jar was 6 ins. The rod clamped in the middle was 9 feet.

The wave length in air $= 4 \times 6\frac{1}{2}$ ins. $=$ 2 feet 2 ins.

" " " beech $= 2 \times 9$ feet $=$ 18 feet.

Number of wave lengths $\times$ length of the wave=speed in feet per second.

$\therefore$ speed in air $=$ 2 feet 2 inches $\times 512 = 1120$ feet per second.
Speed in beech $=$ 18 feet $\times 512 = 9216$ feet per second.

Or we might reason at once :—

$$\frac{\text{The speed in air}}{\text{,, \quad beech}} = \frac{6\frac{1}{2}\text{ ins.}}{4\text{ feet }6\text{ ins.}} = \frac{13}{108};$$

$\therefore$ speed of sound in beech $= 1120 \times \frac{108}{13} = 9216$ feet per second.

42. Kundt's Method of Determining the Speed of Sound in Gases and Solids.

Refer to § 40. A vibrating column of air is able to act upon light powder and show the presence of nodes and segments.

Use a thin tube 10 feet or 12 feet long, 2 inches in diameter; clamp it in the middle; cause it to vibrate.

Scatter lycopodium powder in the glass tube and excite it; the powder arranges itself in heaps. It is thrown from the vibrating parts, and collects at the nodes.

What do these heaps of powder mean? The length of the glass tube is equal to $\frac{1}{2}$ a wave length of the sound wave in glass.

The same sound in air, has sound waves whose nodes are in the positions marked by the heaps in the tube.

Measure the glass tube. It is 10 feet 4 inches long. The distance between the nodes $=$ 8 inches:

$$\therefore \frac{\text{speed of sound in glass}}{\text{,, \quad ,, \quad ,, \quad air}} = \frac{124}{8} = \frac{15 \cdot 5}{1};$$

∴ the speed of sound in glass $= 1120 \times 15 \cdot 5 = 17360$ feet per second.

Take a glass tube 6 feet long, fit a cork *b* into one end, so that it can be moved with a little effort. To a glass rod A′ 6 feet long attach a light cardboard disc (*a*), that fits lightly into the tube; clamp the middle K of the rod securely; dust the inside of the large tube with lycopodium powder. Draw a resined cloth along the rod; the longitudinal vibrations are transmitted to the air in the tube. The powder forms in heaps; these heaps are nodes, as the powder is whirled about at the segments, and accumulates at the nodes on account of its lightness. Move *b* until the heaps are well defined.

The column of air *a b* is set vibrating by the vibrations of the glass rod.

Count the number of nodes, and measure the distance; thus obtain the average distance between two nodes; this equals half a wave length in air $= 4\frac{1}{2}$ inches say.

The wave length in glass (§ 41) $= 4 \times 3$ feet $= 12$ feet;

$$\therefore \frac{\text{speed of sound in air}}{\text{,, \quad ,, \quad ,, glass}} = \frac{9 \text{ inches}}{12 \text{ feet}} = \frac{9}{144} = \frac{1}{16}.$$

By using a brass rod the speed of sound can be ascertained in brass.

Having obtained the speed of sound in brass, lead dry hydrogen into *a b*, and thus calculate the speed of sound in hydrogen.

Refer to table, § 5.

The student will see how such figures can be obtained.

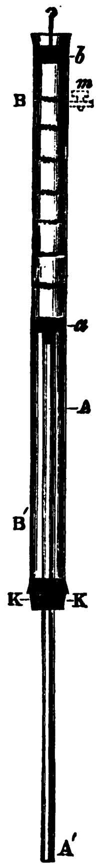


FIG. 90.

EXAMPLES. XIV.

1. Explain the relation between the length of a rod of a given material, and the pitch of a note produced by it under longitudinal vibrations.

2. When rods of the same length, but of different materials, are held in the middle, and rubbed with a resined glove in the direction of their

length, explain why musical notes are produced, and why they are of different pitch.

3. A glass rod 4 feet long is clamped at its centre, and when rubbed from centre to end with a wet cloth, emits a musical note. Explain how this note is produced. What similarity is there, if any, between the mode of production of this note, and the mode of production of the fundamental note of an open organ pipe?

4. Explain a method of comparing the velocity of sound in a rod, with its velocity in air.

5. A musical string vibrates 400 times in a second: state what occurs when you make the length one-third and four times the original length without altering the tension; and also what occurs when the tension is made four times and one-ninth the original tension, without altering its length.

6. The flash of a gun-cotton rocket, exploded at a height of 1000 feet in the air, is seen by a person six miles distant. Some time afterwards the sound is heard. How many seconds elapse between the flash and the sound? One thing which is purposely omitted ought to be taken into account. What is it?

7. What is the cause of the variations of pitch produced by the fingering of the common flute?

8. An open and a stopped pipe are tuned to give the note C. The hearer can detect a difference in the notes. What is this difference and how is it caused?

9. When a cannon is fired, windows are sometimes broken. Why is this?

10. A stretched wire emits in general a different note when it is struck or rubbed cross-wise, from what it produces when it is rubbed length-wise by a resined pad. Explain the difference; and show by a diagram the state of the wire's disturbance in the latter case as regards displacement, and as regards extension and compression at its middle point.

11. A silver and an iron wire of the same diameter, are stretched by weights of 4 and 36 pounds respectively. When plucked transversely they produce the same sound. The density of silver is 10·5 and iron 7·8. Find the lengths of the wires.

12. What is the length in feet of the sound waves, and the number of vibrations per second, of a certain tuning-fork to whose note a tube of air, at normal pressure and temperature (sound speed, 1085 feet per sec.), 12 inches long, closed at the bottom and open at the top, responds?

Show by wave-line figures the air's states of alternate condensation and rarefaction in the tube in the case described, and also when the tube resounds to a fork an octave higher in pitch than the former one.

LIGHT.

CHAPTER I.

RECTILINEAR PROPAGATION OF LIGHT—SHADOWS—PHOTOMETRY.

1. Introduction.

From observation we conclude that light comes from bodies that are burning. Light seems to dance off a piece of looking-glass and then affect our eyes; we know the looking-glass is not on fire. The sea, the surface of a pond at times, looks on fire; we know that this is not in reality the case. The looking-glass and the sea *reflect* the light of the sun.

Bodies from which light proceeds are called *luminous bodies*. If the light be due to the burning of the body, as is the case in the candle and the fire, the bodies are *self-luminous*. Many bodies are like the looking-glass and merely reflect light.

Light proceeds from the sun, and passes through the space between the earth and the sun, through the atmosphere, through clear glass, roughened glass, paper, and other bodies. It is stopped by several sheets of paper, or by brick walls.

A substance through which light passes is called a **medium**.

Substances that allow light to pass, so that objects can be clearly distinguished, are called **transparent**; such are glass, the air, water.

If light pass through substances, but objects cannot be clearly distinguished, the substances are called TRANSLUCENT; such are roughened glass, oiled paper. The metals generally, if in thin layers, are translucent.

OPAQUE SUBSTANCES do not allow light to pass through, as gold, bricks.

A MEDIUM is called *homogeneous*, when its composition and density are the same throughout. Water, carefully prepared glass, the atmosphere if we consider only a small part of it, are homogeneous bodies.

2. PROPAGATION OF LIGHT—RAY AND PENCIL OF LIGHT.

In a *homogeneous medium* light is propagated in straight lines. This is our everyday experience: we never expect to see round a corner. If we wish to see through pinholes made in three pieces of cardboard, we place the holes in a straight line. The sunbeams as they track their way through the room are straight. Any statement affirming that light could be bent, we should reject, unless the experiment could be performed.

The reason, for the insertion of the word homogeneous, will be shown later.

When light proceeds from a luminous point it is supposed to be made up of RAYS. Such rays will of course be straight lines.

A number of rays form a PENCIL of light; as light proceeds in straight lines, the pencil will generally be a cone, or a cylinder if the rays be parallel.

Place in the stage of a magic lantern, a blackened card with a hole in the centre, $\frac{1}{8}''$ in diameter; focus the image of the hole on the wall. Hold a piece of smouldering paper near, and notice the cone of light. Imagine this cone to be made of an enormous number of rays.

Examine a pencil of light from the sun, passing through a hole in a shutter; the rays are parallel; the pencil is a cylinder.

3. SHADOWS—UMBRA—PENUMBRA.

It follows, that if light travel in straight lines, part of the space behind an opaque body, is protected from the source of light in front of it; the opaque body casts a shadow.

Use a candle or a lamp as a source of light, a square piece of cardboard 1 inch side for the opaque body, a square of translucent paper (ordinary foolscap) for the screen. Turn the edge of the flame to the cardboard. The centre of the shadow is very dark; round the edge, the darkness is not so marked. Make pinholes in various parts of the screen, and look at the light, through the pinholes, from behind the screen. Through the pinholes in the darkest part, no part of the flame can be seen; through the medium darkness of the border, *part* of the flame can be seen; that is, this part is *partly* illuminated by the flame.

The part of the shadow, from which no part of the luminous body can be seen, is called the UMBRA; the part, from which a portion of the luminous body can be seen, is called the PENUMBRA.

Examine the cases when the object is greater than, equal to, and less than the source of light.

Object Greater than the Source of Light.

Use a ball M as the object; place a black screen, with a small hole *ba*, in front of the lamp; the light appears to come from *ba*.

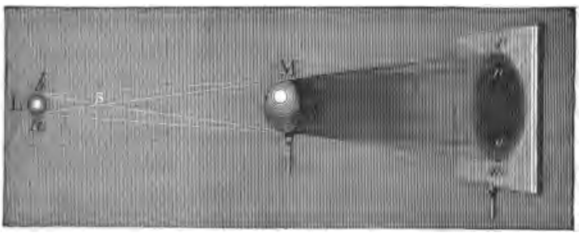


FIG. 91.

The umbra is in all cases greater than the object, and the shadow will increase in size, as the screen is moved away.

Object Equal to the Source of Light.

Use the lamp with a ground globe, and a ball of equal size. The umbra will remain the same size as the object, at whatever distance the screen is placed.

Object Smaller than the Source of Light.

Apparatus, a lamp S with a ground globe, a ball E, a small ball M, and a screen.

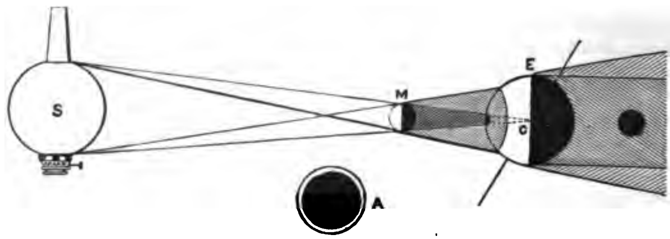


FIG. 92.

The umbra is always smaller than the opaque body; it decreases in area as the screen is moved away, and beyond C only penumbra will be seen.

Test these results by using the screen, and by observing through pinholes.

4. ECLIPSES.

The sun is larger than the earth; the moon is smaller than the earth. When the *umbra* of the moon falls on the earth, an eye placed in the umbra, will be unable to see any part of the sun. Total eclipse is produced. Where the *penumbra* falls, there will be partial eclipse; part of the sun will be seen. In fig. 92 S represents the sun, M the moon, E the earth. The objects and distances are not constructed to the proper scale.

Place a screen in the position of the earth, and examine the appearance through the pinholes. Move the screen away from S; beyond C, all will be penumbra.

A person, in this penumbra, will see a black circle surrounded by a bright ring A; an annular eclipse is produced.

If the moon pass into the shadow, cast by the earth, an observer on the latter will see the moon eclipsed, partially if it be partially in the shadow, totally if it be entirely in the shadow. We also learn that the moon is not self-luminous; it merely reflects the sun's light.

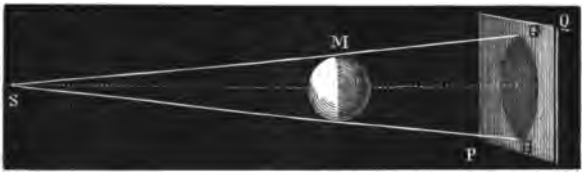


FIG. 93.

As we reduce the size of the source of light, the penumbra is reduced. If the luminous body were a point, there would be no penumbra (fig. 93).

5. INTENSITY OF LIGHT.

The quantity of light received on a unit of surface (a square foot or square inch), is called its intensity.

Seeing that light is propagated in straight lines, it follows, as in the case of sound and heat, that its intensity diminishes inversely as the square of the distance from the source of light.

Illustrate this law in this way :—

Suppose the light to come from a luminous point. We can approximate to this by placing in front of a flame, held sideways, a sheet of blackened paper with a hole made by a needle, and regard the hole as the source of light, or cover the lantern with a cap, in which is a small hole. A candle may be used for a rough experiment (fig. 94).

Place a square of cardboard A, of 1″ side, one foot from the hole, or the candle; and a white screen B two feet away; the shadow is 2″ side, therefore 4 square inches in area.

If the small piece of cardboard be now removed, the 4 square inches of screen in shadow, at a distance of 2 feet, will receive the

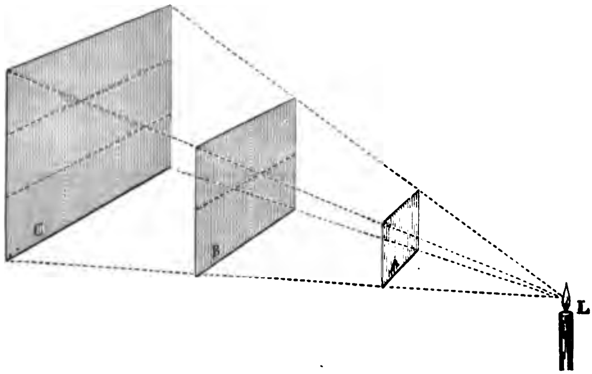


FIG. 94.

light that 1 square inch received at a distance of 1 foot. Try various positions and measure.

Distance of object	Size of object	Distance of shadow	Size of shadow
1	1	2	4
1	1	3	9
2 (B)	4	3 (C)	9

By doubling the distance the intensity becomes one fourth.
By trebling „ „ „ „ „ ninth.

The intensity of light at distance 2 : the intensity of light at distance 3

as $\frac{1}{4} : \frac{1}{9}$.

In the above positions incline the screen ; a greater portion is in shadow ; i.e. if the square were removed, a greater portion of the screen would be illuminated, and therefore the intensity would be diminished.

The intensity varies inversely as the square of the distance from the luminous body.

The intensity changes with the inclination.

EXAMPLES. I.

1. Explain the terms pencil, ray, medium.

2. What is meant by the umbra and penumbra of a shadow? How could you show by experiment that from the penumbra, part of the luminous body can be seen?

3. A small ball is held before a luminous point; draw and describe the form of the shadow on the wall. Will there be a penumbra? Replace the luminous point by a luminous area. What effect will this have on the shadow?

4. Describe and illustrate a total eclipse of the sun. A person sees a partial eclipse; is he in the umbra or penumbra of the shadow?

5. Suppose light proceeds from a luminous point 12″ distant from a screen: a piece of square cardboard 4″ side is held parallel to the screen, 4″ from the luminous point. Find the area of the shadow.

6. In No. 5 the screen is inclined to the cardboard; how does this affect the area of the shadow?

6. PHOTOMETRY.

The law of inverse squares leads to a useful result.

Take a cylinder of wood 18 inches high, 1 inch diameter; a square of white cardboard 2 feet side; a lamp or gas flame, and a candle. Place the cylinder near the screen, and the candle at a distance of 18″ from the screen. The lamp or gas flame should be the same height as the candle flame. Move the lamp until the shadows of the cylinder appear side by side, and equally dark (fig. 95, A).

Now, as the candle illuminates S_1 and the lamp illuminates S_2 (fig. 95, B), the candle and the lamp cast the same quantity of light on the screen. And, as the quantities of light received at S_1, S_2 are equal, by the law of inverse squares, the illuminating power of the lamp, is to the illuminating power of the candle, as the squares of their distances from S_2 and S_1.

Measure the distances. $L_1 S_2 = 59$; $L_2 S_1 = 24$.

Then illuminating power of L : illuminating power of C

$$\text{as } L_1 S_2^2 : L_2 S_1^2, \text{ as } 59^2 : 24^2, \text{ as } 3481 : 576, \text{ as } 6{\cdot}04 : 1.$$

The light of the lamp is equal to the lights of 6 candles.

This instrument is *Rumford's Shadow Photometer*.

A *photometer* is an instrument for measuring the comparative intensities of lights.

A.

B.

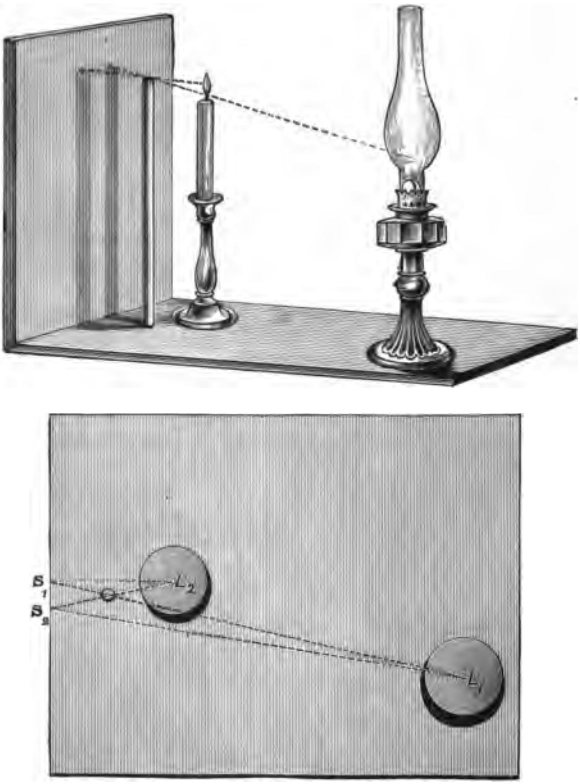


Fig. 95.

The lamp and candle should be at a greater distance from the screen than is shown in the drawing.

7. Bunsen's Grease-Spot Photometer.

Make a grease-spot on a sheet of paper. Place the paper between your eye and the light; the spot is seen by transmitted

light, and appears light on a dark ground. Place it against the wall, so that the light falls on it. The spot is seen by reflected light, and appears dark on a light ground.

If the light falling on both sides of the paper, be of the same intensity, the spot appears the same as the surrounding paper. This experiment illustrates the principle of Bunsen's photometer.

To Make a Bunsen or Grease-Spot Photometer.

Cut two circular (or square) frames of cardboard, 7″ outside measurement, 5″ inside; stretch a circular piece of writing-paper 6″ diameter, and paste it on one frame. Paste the other frame and place it above the paper; press and leave it to dry. Drop in the centre of the paper a spot from a stearine candle; after a few minutes remove it with a knife. Place the paper between two pieces of blotting-paper, and run over the blotting-paper with a hot iron or warm piece of glass. Trim the edges. Make a slit in a rod of wood, fix the frame in this; insert the rod in a block 3″ × 2″ × 1″. The grease-spot should be 8″ from table. Divide a line on the table into inches. Place the photometer as in fig. 96. The wick of the candle and the gas flame should be the same height.

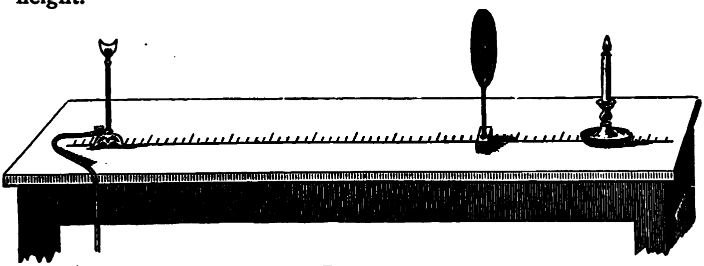


Fig. 96.

To compare the intensity of a gas flame with a candle flame, move the photometer until the spot cannot be seen; the illumination on each side is now the same. Remember the law of inverse squares:

Distance of gas		35″,
„	candle	9″;

∴ illuminating power of candle : illuminating power of gas

$$:: 9^2 : 35^2,$$
$$:: 81 : 1225,$$
$$:: 1 : 15 \cdot 1.$$

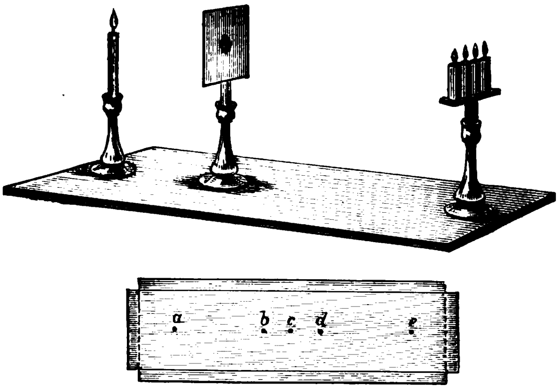
The gaslight is equal to the light of 15·1 candles.

The reports concerning the illuminating power of gas are obtained by the above methods.

The standard candle is a sperm candle, 6 to the lb., burning at the rate of 120 grams in an hour.

To Verify the Laws of Inverse Squares.

Cut a piece of tin the shape of fig. 98; turn up the edges at the dotted lines; make five holes *a b c d e*. Place tacks through *a b d e* and solder them; fasten the tray to a rod, by passing a tack through *c*.



Figs. 97, 98.

Cut five pieces of candle from the same candle; place four on the tacks in *a b d e*, the fifth on a single stand : trim carefully, so that the wicks are the same size; place four on one side of the photometer, the single candle on the other side (fig. 97).

Find the distances at which the spot disappears. The four candles should be at twice the distance of the single candle from the screen.

EXAMPLES. II.

1. Describe an experiment, made with the shadow photometer, to test the illuminating powers of two sources of light.

2. State, and explain, the relation between the intensity of the light, which falls on a given surface, and the distance of the source of light from the surface.

3. Of two gas flames, one gives out 25 times as much light as the other. If you test their illuminating powers by means of a Rumford's (shadow) photometer, and you place the smaller flame at a distance of two feet from the screen, at what distance from the screen must the larger flame be placed, in order, that the shadows of an opaque object cast by the two flames, may be equally illuminated?

4. If you hold a sheet of blotting-paper, in the middle of which a grease-spot has been made, first behind and then in front of a gas flame, you will notice a difference in the appearance of the grease-spot. What is this difference? How would you use such a piece of blotting-paper to compare the illuminating power of a small gas flame with that of a large one?

5. Explain the principle of the Bunsen (or grease-spot) photometer. How would you prove that the illumination of any surface is inversely as the square of its distance from the source of light?

6. In fig. 94 if A be a disc 2″ diameter, 3″ from the luminous point, what shape and size will the shadow B be, when it is 7″ from the point?

8. IMAGES PRODUCED BY SMALL APERTURES.

Pinhole Camera.

Knock the bottom out of a coffee tin, blacken the inside, cover one end with tinfoil; make a cylinder of cardboard that just slides inside the tin; cover one end of this with tissue paper and push it into the tin. Make a pinhole in the centre of the tinfoil, look into the box, pointing it to some illuminated object (trees, houses, etc.) By adjusting, an inverted image is seen on the tissue paper. Make another hole in the tinfoil, another image appears; make more holes, the images overlap and become indistinct; remove the tinfoil, the paper is uniformly illuminated. That is, the uniform illumination can be regarded as the result of a number of images overlapping each other.

In order to show this to a class, remove objectives and condensers from a magic lantern, cover the aperture with a cap of tinfoil, prick one hole, and an image of the lamp wicks is seen. By pricking more holes, the above effects are obtained.

Light proceeds in straight lines from the trees, etc.; these lines cross at the hole, with the result that the image is inverted. Fig. 99 illustrates the formation of images through a small aperture. The shape of the image does not depend upon the shape of the aperture. In the covering of the camera or the lantern, make a small hole with a triangular piece of iron (file the end of a needle); the image does not seem different from the image obtained in the previous experiment. Let sunlight enter the triangular aperture of the camera; by pushing in the inside tube, a *triangular image* is obtained. Darken the room, and let the light from the sun, after passing through the aperture,

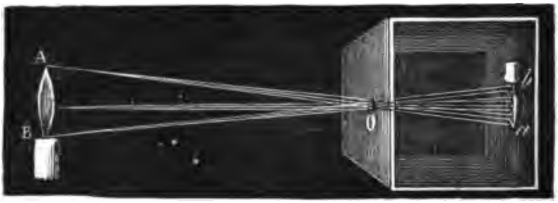


FIG. 99.

fall on the wall, at some distance from the aperture; the image is *round.*

Every point on the surface of the sun prints its own triangular image. When the screen is near the hole, these images nearly coincide and a triangular image is formed. When the screen is moved away to a distance, the triangular patches are spread over a larger space; the overlapping of those in the middle of the space gives a bright patch. Every point in the circumference of the sun will give a triangular patch in the circumference of the space; these overlapping form a circular boundary.

9. LIGHT IS IN ITSELF INVISIBLE.

The rays of the sun are seen on account of the pieces of dust that float in the air; if these were removed the beam would be invisible. The particles of dust and smoke reflect the light.

In a darkened room take a tall glass jar; arrange, so that a beam of light from the sun, or a parallel beam from the lantern, is reflected from a small mirror vertically into the jar; cover the jar with a glass plate; look at the jar and notice how feeble is the illumination. Place a piece of smouldering paper in it. As the smoke forms, the jar seems to fill with diffused light; remove the plate, and as the smoke disappears streaks of darkness appear. Hold smouldering paper in the path of a sunbeam; the space seems to brighten. Allow a beam of light to pass through distilled water in the jar; it is scarcely apparent: add a little milk to the water; the path of the beam is distinct.

EXAMPLES. III.

1. If you make a pinhole in the bottom of a box, and replace the lid by a piece of tissue paper, you see on the paper pictures of external objects. Explain the formation and character of the pictures.

2. Is the expression 'I see a sunbeam' scientifically correct?

3. When sunlight passes through the spaces between the leaves of trees, circular patches of light are seen on the ground. Why?

4. You cannot see the shadow of a hair held at a foot distance from a wall, against which the sun is shining; whereas you see the shadow when the hair is held close to the wall. What is the reason?

5. The centre of a luminous sphere $\frac{1}{2}''$ diameter, is $3''$ from the centre of an opaque sphere $1\frac{1}{2}''$ diameter. Sketch the shadow on a screen $6''$ from the centre of the luminous sphere.

CHAPTER II.

REFLECTION OF LIGHT—PLANE MIRRORS.

10. Reflection of Light.

When light falls upon a piece of looking-glass or bright metal, it seems to start off; the light is reflected. The reflection of the sunlight is seen from the surface of water.

Use a piece of looking-glass (L) 2″ side, and a semicircle of cardboard 1 foot radius, divided as in fig. 100. Place the semicircle vertically; glue it to large corks, so as to keep it in that position. With a reflector M send a beam of light so that it strikes the look-

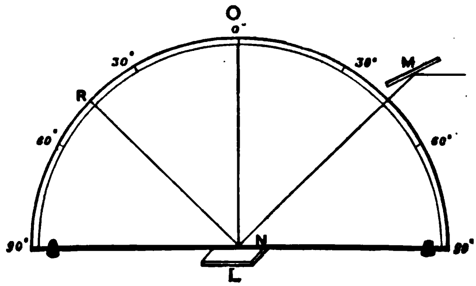


Fig. 100.

ing-glass, near the point where the line N meets the glass and parallel to the plane of the semicircle. Hold smouldering paper near the path of the beam; read the angles from O.

The ray that strikes the glass is called the incident ray; the ray that is reflected, the reflected ray. A line perpendicular to a surface at a point, is called the normal at that point; it is represented by N O.

The angle M N O, which the incident ray makes with the normal, is called the ANGLE OF INCIDENCE. The angle R N O, which the reflected ray makes with the normal, is called the ANGLE OF REFLECTION. Measure the angles in a few cases.

Angle of incidence	Angle of reflection
40	40
60	60
20	20

We conclude that—

(1) The angle of incidence equals the angle of reflection.

(2) That in whatever position the incident ray meets the mirror, the sheet of cardboard (a plane) can be so placed that it passes through the incident ray, the reflected ray, and the normal.

The laws were demonstrated by observing the actual path of the rays, the rays being made visible by allowing smoke to appear in their path. The experiment can be varied in this manner, in ordinary daylight.

Stick a pin with a large bright bead for a head, at any part of the circumference of the divided circle. Blacken a piece of glass tubing, and move this, until by looking through it, at the mirror, the image of the pin-head is seen.

If the pin be at 45° on one side, the tube will be 45° on the other side, and the line joining the pin's head to the mirror, the line joining the eye to the mirror, and the normal will be in one plane.

When the incident beam made an angle of 40° with the normal, there was an angle of 80° between the incident beam and the reflected beam. When the angle was 30°, the angle between the two beams was 60°. By making the angle between the incident beam and the normal 10° less, the angle between the two beams was made 20° less.

By keeping the incident ray fixed, and moving the mirrors, we shall find that by moving the mirror through, say, 5°, the reflected ray moves through 10°.

If a mirror be made to rotate, the reflected beam moves through twice the angle passed over by the mirror.

Laws of Reflection.

(1) The angle of incidence is equal to the angle of reflection.

(2) The incident ray, the reflected ray, and the normal are in the same plane.

11. Regular and Irregular Reflection—Diffusion.

In an otherwise darkened room, allow sunlight, or a lantern beam, to fall in succession upon a piece of looking-glass, a sheet of tin, a sheet of white cardboard, and a sheet of blackened cardboard.

From the looking-glass a distinct spot of light is obtained on the wall; the surface of the looking-glass cannot easily be seen unless the eye be in the path of the reflected rays. The sheet of tin gives a fairly distinct spot; its surface can be seen more readily from any part of the room, than that of the looking-glass. The sheet of white cardboard gives no distinct spot; it can be seen distinctly from any part of the room. The black sheet of cardboard does not reflect at all.

Mirrors, polished sheets of metal, are called good reflectors; they reflect light in a definite manner. The surfaces are smooth. Sheets of cardboard reflect light *irregularly*; the rays are diffused and strike the eye in any part of the room. Blackened cardboard and similar bodies are bad reflectors.

The looking-glass and, to a less extent, the polished tin reflect light regularly. The white cardboard reflects light irregularly; in a similar way the trees, furniture, etc., diffuse the light that falls upon them.

12. Application of the Laws of Reflection—Plane Mirrors.

Having satisfied ourselves, that the laws of reflection are true, we can use them to determine what will actually occur under certain conditions, even without performing the experiment. We shall be further convinced of the accuracy of these laws, if we find, that the results we obtain by using them, agree with the actual facts.

Let S S be a reflecting surface, *a* a luminous point; rays proceed in straight lines in all directions from *a*. Draw a few of these rays, *a b*, *a c*, *a d*, *a e*, *a f*. Trace by geometry the reflected rays.

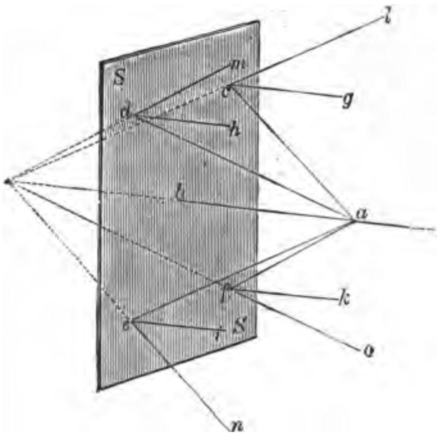


FIG. 101.

In each case draw the normals (*b a*, *c g*, etc.), and remember the laws of reflection (fig. 101).

Produce the reflected rays behind the mirror; they all meet in a point *a'*. The reflected rays seem to come directly from the point *a'*. By measurement

$$ba' = ba.$$

a' is called the optical image of the point *a*.

The image is on the perpendicular produced, drawn from the object to the reflected surface, and is as far behind the surface as the object is in front.

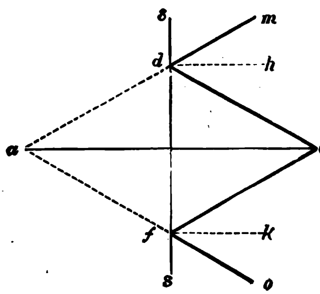


FIG. 102.

To represent the whole of a reflecting surface is inconvenient; imagine it cut by a plane passing through *a b a'*, its representation then will be as in fig. 102.

13. TO TRACE THE RAYS FROM A POINT TO THE EYE.

FIG. 103.

A is the luminous point, O the eye, N M the reflecting surface.

The image of A is at *a*, A *a* is perpendicular to N M, and N A = N *a*.

Join *a* to the extreme points of the eye; then all rays are between the cone of rays, of which the section is shown.

The rays *really* proceed from A.

Join A B, A C.

The path of the rays is A B O, A C O.

Remember we *see* the bodies, in the direction, in which the rays enter the eye.

TO DRAW THE IMAGE OF AN OBJECT A B.

All bodies are made up of points, and the image will be the image of an assemblage of points.

The image of A is first obtained, then the image of B; the images of intermediate points must lie between *a* and *b*.

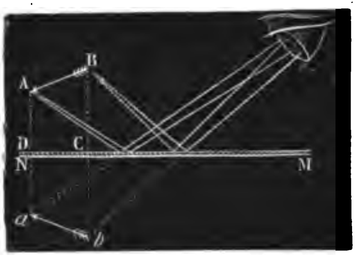


FIG. 104.

It is also plain that by doubling C D A B over on C D *a b*, the figures will coincide; that is, *the image is the same size as the object.*

The images in the above cases have no actual existence; they cannot exist behind the opaque mirror. Such images are called *virtual images.*

The course of the pencil of rays can be traced as in fig. 103.

In fig. 102, if *d f* be regarded as the reflecting surface, the eye must be placed between the lines *a d*, *a f*, produced, in order to see the image *a*. Suppose C M to be the reflecting surface in fig. 104: to see *a*, the eye must be between *a* C and *a* M produced; to see *b*

the eye must be between *b* C and *b* M produced. Therefore to see the whole of *a b*, the eye must be between *a C* and *b M* produced.

Lateral Inversion.

If we stand in front of a plane mirror, our right hand appears as the left hand of the image. This is termed lateral inversion. As a result of this if we write on paper, blot it with the blotting-paper, and hold the blotting-paper in front of a mirror, the writing can be read. Type set up, can be read by reflection, by holding it in front of a mirror.

14. Inclined Mirrors.

Take two square pieces of looking-glass (about 1 foot side); varnish the backs or cover with cardboard; fasten cardboard to three sides with paste and black ribbon. Join two edges by a piece of black ribbon to make a hinge.

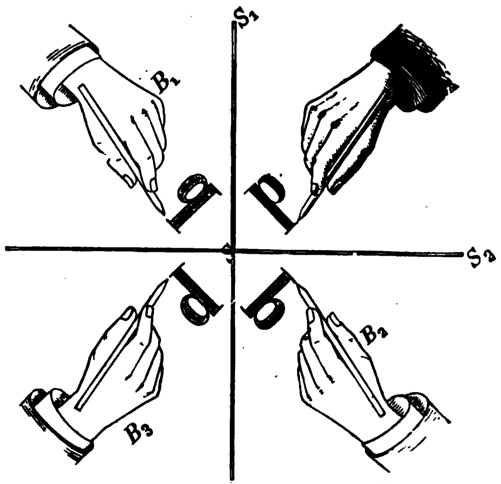


Fig. 105.

In fig. 105, $S S_1$, $S S_2$ are horizontal sections of the mirror. Place the mirrors at right angles to each other, each standing upright on a sheet of white cardboard. Print the letter *p* as in

the figure. The letter is reflected in the mirror $S S_1$ at B_1, and in the mirror $S S_2$ at B_2; the image B_1 is reflected in the mirror $S S_2$, and the image B_2 in the mirror $S S_1$. If the hinge be a good one, an image B_3 will be seen. Draw the above with instruments, using the laws of reflection. The images of B_1 in $S S_2$, and B_2 in $S S_1$, coincide, so that only one image, B_3, results.

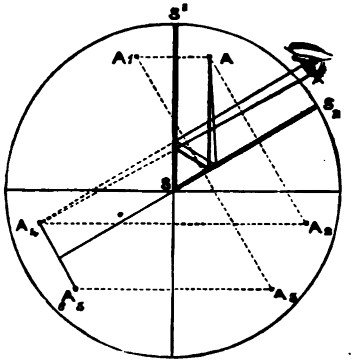


FIG. 106.

Notice the lateral inversion in B_1 and B_2, but that there is no lateral inversion in B_3.

Arrange the mirrors so that they form an angle of 60°. Count the images; draw the figure (fig. 106). For simplicity a luminous point is taken. The images coincide at ${}_6A_5$. As an exercise, the path of the rays by which A_4 is seen is drawn.

A is reflected in $S S_1$ as A_1, A_1 is reflected as A_3 in $S S_2$, &c.

Angle of inclination of mirrors	Figure + images
90°	$1 + 3 = 4 = \frac{360}{90}$
60°	$1 + 5 = 6 = \frac{360}{60}$
45°	$1 + 7 = 8 = \frac{360}{45}$

To find the number of *images* formed by inclined mirrors, divide 360 by the number of degrees in the angle of inclination, and deduct one from the quotient.

THE KALEIDOSCOPE is an instrument made by placing two strips of glass in a tube, so that they are inclined at an angle of 60°; the end of the tube is closed by a piece of roughened glass; on this is placed pieces of bright coloured glass and beads, kept loosely in their places by a sheet of plane glass. On looking in at the other end, and holding the tube to the

light, various coloured images are seen, formed by reflection in the inclined mirrors.

15. Parallel Mirrors.

If mirrors be placed parallel to each other an infinite number of images would be seen if the source of light were sufficiently bright and the mirrors of perfect polish. This result is best seen when standing between two large mirrors. The student should calculate the number of images when the inclination of the mirrors is 5°, 1°, $\frac{1}{2}^\circ$, $1'$, $1''$, $\cdot 0001''$, 0°.

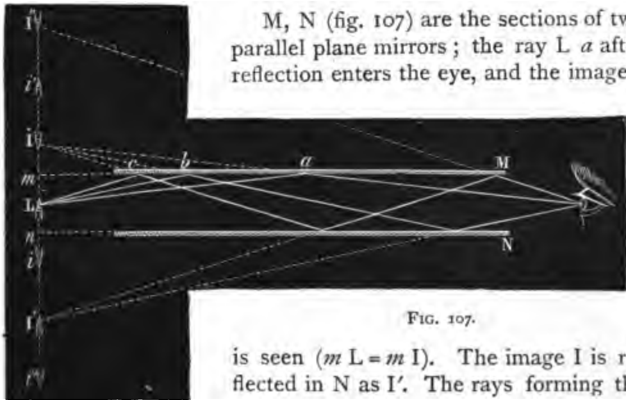


Fig. 107.

M, N (fig. 107) are the sections of two parallel plane mirrors; the ray L *a* after reflection enters the eye, and the image I is seen ($m\,L = m\,I$). The image I is reflected in N as I′. The rays forming the image, enter the eye after two reflections; that is, the ray L *b* after reflection from M and from N gives the image I′ ($n\,I' = n\,I$); the ray L *c* after three reflections gives I″. The images *i*, *i*′, and *i*″ are similarly formed by rays reflected in the first instance from N.

While there is no limit theoretically to the number of images, practically the images become so faint, on account of the loss of light, that only a small number can be distinguished. The greater the illumination, the better will the images be seen.

Examples. IV.

1. Explain by aid of a diagram how a person can see a complete image of himself, in a plane mirror one half his height.

2. A person sees his image, in a looking-glass inclined to the floor at an angle of 30°; show by a drawing the size and position of the image.

3. When an object is placed between two plane mirrors, explain, how changes of position will affect the number and positions of the images of the object, seen in the mirrors. Trace the path of a beam which is reflected as many times as possible by two plane mirrors inclined at an angle of an equilateral triangle.

4. A person is equidistant from two plane mirrors, which meet in the corner of a square room. Explain in what way the image of himself, which he sees when looking towards the corner of the room, differs from the images which he sees, when looking towards the sides of the room.

5. I stood yesterday beside a muddy lake with the sun behind me. My shadow was thrown distinctly upon the water. I stood afterwards beside a clear, deep lake, with the sun likewise behind me, and saw no shadow. Explain these observations.

6. When the sun was overclouded, as I stood beside the muddy lake, my shadow disappeared; but the images of trees on the opposite bank of the lake did not disappear. Explain the reason.

7. A sunbeam passes through a darkened room: when the blackest smoke is caused to cross the beam it appears white to an eye placed in the darkness. Explain the effect.

16. Reflection from Transparent Bodies.

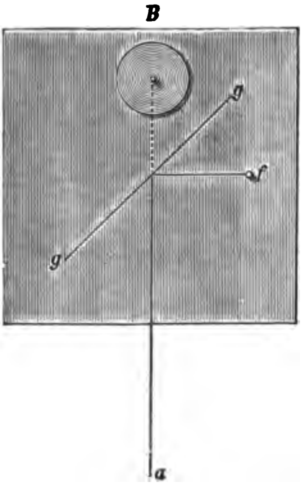


Fig. 108.

On looking at a window pane obliquely, not only are objects outside the room seen, but the images of curtains, and bodies inside the room, appear among the real objects outside.

If the curtains were brightly illuminated and we did not know the glass was there, we might believe the curtains were actual objects outside. This is the explanation of all the so-called *ghost experiments*. The objects are strongly illuminated, and their images are reflected by clear glass that is unobserved by the spectator.

Take a square board 1 foot side; imagine it to be the bottom of a cube, fix a sheet of window glass *gg* vertically along a dia-

gonal. Make one side of the cube (the side cut by the line *a*) with a square sheet of black cardboard, in the centre of which is cut a square hole 4″ side. Place a bottle full of water behind *g g* (the plan of the bottle is shown) and a lighted candle *f* as in the figure (fig. 108).

An observer some distance in front, looking through the square hole, will see the bottle, by *direct* light, and the candle by *reflected* light. The burning candle appears to be inside the bottle of water. All other lights should be extinguished.

17. Reflecting Powers of Bodies.

The reflecting power is different in different reflectors; it also varies with the angle of inclination. By holding a sheet of foolscap near the flame and looking at the paper obliquely an image of the flame can be seen.

Comparison of the Reflecting Powers of Water and Mercury.
Rays reflected in 1000.

Angle of incidence	Mercury	Water
0° (perpendicular)	666	18
40°	—	22
60°	—	65
80°	—	333
$89\frac{1}{2}$°	721	721

The remaining part is either reflected irregularly, or it is absorbed by the substance used.

Examples. V.

1. What is meant by lateral inversion?

2. Give a sketch of a candle shedding light through two long narrow tubes, and then show in the sketch how two flat mirrors are to be placed so as to reflect the light which has come through the tubes upon one and the same spot.

3. A luminous point on a level with the eye is placed between two plane vertical mirrors which are inclined to one another; trace the path of a pencil of rays by means of which the luminous point will be seen after three reflections.

4. When a plane mirror is turned about an axis in its own plane, explain the change of position of the image of a small object seen by reflection in the mirror, and point out its relation to the laws of reflection of light.

5. Two plane mirrors are inclined to one another at an angle of 72°; explain in what way the position and number of images of any object between the two mirrors is limited.

6. What must be the angle between two plane mirrors, in order that an incident ray which is parallel to one of them may, after two reflections, be parallel to the other?

7. Smoke the outside of a glass tube. Cover one end with tinfoil and prick a pinhole in the centre of the tinfoil; look through the other end a a candle. Explain the formation of the concentric circles of light.

CHAPTER III.

SPHERICAL MIRRORS.

18. MANY MIRRORS ARE PARTS OF A SPHERICAL SURFACE.

LET fig. 109 represent the section of a spherical shell through the centre. If a small part of the surface A B be taken, A B

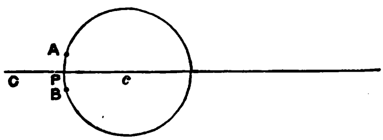


FIG. 109.

is the section of a spherical mirror. If the surface nearer *c* reflect light it is called a *concave mirror* ; if the surface nearer C, it is called a *convex mirror.* The line *c* C is called the principal axis of the mirror ; *c* is the centre of curvature. P is the apex of the mirror, and *c* P the radius of curvature.

19. THE FOCUS.

With a radius of 6″ describe a small arc A B, so that angle A C B is not greater than 20°. Draw a number of lines S A, T L, X B parallel to C O, the principal axis.

Join A C. We can conceive that a small portion of the surface at A is a plane. The radius at A will be the normal. By the laws of reflection the reflected ray will be A K cutting the axis at F (angle C A K=angle S A C). In the same way treat the incident ray T L: the reflected ray by construction again passes through F.

Any number of incident rays, parallel to the principal axis, after reflection pass through the same point F in the principal

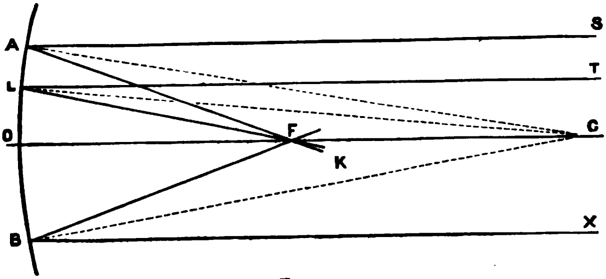


FIG. 110.

axis. We also conclude that rays passing through the focus, are parallel to the principal axis after reflection.

The point on the principal axis where rays parallel to the axis cut the axis after reflection, is called the FOCUS *of the mirror.*

By measurement F O = F C. The focal distance of a concave mirror is half the radius of curvature.

A ray from C to any point will be reflected back through C, just as a ray incident on a plane mirror perpendicular to the surface is reflected perpendicularly.

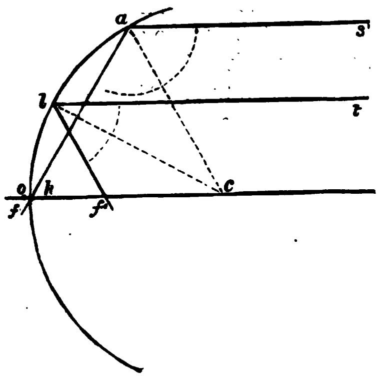


FIG. 111.

Describe a large arc of 2″ radius (fig. 111); repeat the same construction as in fig. 110.

There is *no* point in the axis through which all rays parallel to the axis pass after reflection.

In treating of mirrors the arc is always supposed to be small compared with the radius of curvature. For distinctness in diagrams the size of the arc is frequently exaggerated.

20. Conjugate Foci.

Light from a point L falls on a mirror and is reflected to *l*. C is the centre of curvature; A the vertex. A multitude of rays from L would strike the mirror; only two are drawn. If the aperture be small all would practically come through *l* after reflection.

Fig. 112.

l is the image of L.

If *l* were the source of light, by the laws of reflection the image would be at L.

l and L are called conjugate foci.

Let u = the distance of the object from the mirror, v = the distance of the image, f = the focal distance, r = the radius of curvature.

The sum of the reciprocals of the distance of the object and image from the mirror, is equal to the reciprocal of the focal distance.[1]

$$\therefore \frac{1}{u} + \frac{1}{v} = \frac{2}{r} = \frac{1}{f}.$$

Suppose the focal distance of a mirror be 10 inches, and that an object is placed on the principal axis 30 inches from the mirror. Then the reciprocal of the distance of the object is $\frac{1}{30}$, the reciprocal of the focal distance $\frac{1}{10}$.

$\therefore$ the reciprocal of the distance of the image $= \frac{1}{10} - \frac{1}{30} = \frac{1}{15}$. The image is 15 inches from the mirror.

---

[1] If MA be very small compared with LA, LM and *l*M will be almost equal to LA and *l*A.

$$lA = v \quad LA = u. \quad CA = r = 2f \text{ (focal distance)}$$

$$LM : Ml :: LC : lC \qquad \therefore LM \times lC = CL \times Ml$$

$$LM = LA \text{ (very nearly)} = u \qquad LC = LA - CA = u - r$$

$$lM = lA \quad ,, \quad ,, \quad = v \qquad lC = CA - lA = r - v$$

$$\therefore u(r - v) = (u - r\ v \qquad ur - uv = uv - rv$$

$$\therefore u + v = \frac{2uv}{\;}$$

$$\therefore \frac{1}{v} + \frac{1}{u} = \frac{2}{r} = \frac{1}{f}.$$

21. The Position and Size of the Image Determined by Construction

The image of an object having dimensions is found by considering it made up of a number of points.

The point A is reflected in the mirror; select two principal rays (fig. 113).

1. The ray A*d* parallel to the axis. This after reflection passes through *f* as *dfa* (§ 19).

2. The ray A*ce* passing through the centre *c*. This is reflected back through *c*. The radius being the normal to the surface.

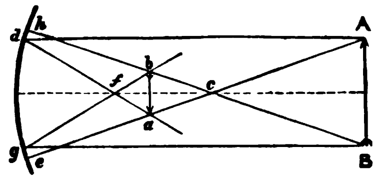


Fig. 113.

These rays intersect in *a*.

All rays from A *will intersect in a if the aperture be small.*

a is the image of A. Similarly *b* is the image of B. The image of all points between A and B will be between *a* and *b*. The image is inverted and less than the object.

The line A*ca* is called the secondary axis of the point A.

It must be remembered that we are only justified in using the above constructions when the distance *he* is small compared with the radius of curvature.

The position of the image has been determined by practical geometry. This determination will be correct if—

(*a*) Light move in straight lines.

(*b*) The laws of reflection be true.

Every time therefore we succeed with experiments, we are strengthening our belief in these two statements.

22. To Find the Radius of Curvature of a Concave Mirror.

1. Hold the mirror so that the light from a distant object (the sun) is reflected; the rays are parallel and the image is at the focus; measure the distance of the focus from the mirror; twice this distance equals the radius of curvature (§ 19).

2. Rays from a distant object are practically parallel. Tie two threads 20 feet long to the same nail; stretch them, placing the other ends within 4 inches of each other. The threads diverge, but if all save a few inches be covered up, it is difficult to detect the divergence.

The image of a distant object is practically at the focus. Therefore, remove a light as far away as possible from the mirror, focus it, or a distant house, on a screen, and measure.

3. The image and object coincide, if the object be at the centre. If the object be a little to the right of the principal axis, the image will be a little to the left.

Take a screen of white cardboard; clamp it; fix the mirror; place the edge of the candle as close as possible to the screen, a little to one side of the principal axis.

Only part of the spherical surface must be used, otherwise distortion is produced. Cover, therefore, all the mirror save a small central portion with black paper. In obtaining an image, push the wick of the candle outside the cone of flame; the image of the glowing wick can be obtained with considerable accuracy.

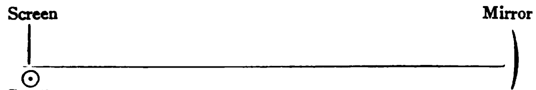


FIG. 114.

Move the mirror until the image is obtained on the screen (fig. 114); the distance from the screen to the mirror = the radius of curvature (r).[1] $\frac{r}{2}$ = the focal distance.

Experiment with a mirror, and compare the results of the three methods.

23. To Find the Relative Positions of the Image and the Object.

Draw a long line on a table and divide it into inches. Place the mirror so that its apex is over 0. Indicate on the scale the positions of the focus and the centre.

[1] If $u = v$, then $\frac{1}{u} + \frac{1}{u} = \frac{2}{r}$; $\therefore \frac{2}{u} = \frac{2}{r}$; $\therefore u = r$.

Place a candle, the height of the centre of the mirror, at the centre of curvature, and the screen as before.

1. Gradually move the candle towards the focus; the screen must be moved away from the centre (fig. 115).

FIG. 115.

An inverted image, that increases in size as the candle is moved towards the focus, is obtained. Use an ordinary magnifying glass, and magnify the image on the screen. If the eye be so placed, that the image is between the eye and the mirror, the image can be seen when the screen is removed. Measure the distance of the object and the image from the mirror in a few cases. As the candle reaches the focus, the image cannot be received on the screen.

2. Return to the positions at the centre of curvature.

FIG. 116.

Move the candle away from the mirror; an inverted diminished image is obtained on the screen, between the focus and the centre. When the candle is at a great distance, the image is at the focus. Measure in a few cases. (Fig. 116.)

3. Place the candle at the focus, and move it towards the mirror; no image can be received on the screen; an upright image is, however, seen in the mirror.

Verify the statement, that the positions of the candle and the image are convertible.

EXAMPLE OF MEASUREMENTS.

Focal length of mirror	§ 22, method 1	. .	7·9 inches
	,, ,, 2	. .	8 ,,
	,, ,, 3	. .	8 ,,

Average focal length = 8 ins.

Distance of object from mirror $= u$	$\frac{1}{u}$	Distance of image $= v$	$\frac{1}{v}$	Value of $\frac{1}{u}+\frac{1}{v}=\frac{1}{f}$	Value of f
40·5	·025	10	·10	·125	8
22·2	·045	12·5	·08	·125	

Columns 1 and 3 are measurements. Columns 2 and 4 are calculations

The values of $\frac{1}{u}+\frac{1}{v}$ are calculated; thus $\frac{1}{f}$ is determined. $\therefore f=8$. This agrees with the value of f obtained directly by the three methods.

The formula $\frac{1}{u}+\frac{1}{v}=\frac{1}{f}$ is also true for *virtual images*, if we remember, that if from the mirror towards the centre be positive, then the distance measured from the mirror, along the axis produced behind the mirror, will be negative.

The formula with this change becomes

$$\frac{1}{u}-\frac{1}{v}=\frac{1}{f}.$$

EXAMPLES. VI.

1. The radius of a concave reflector is 20 inches; calculate the focal length. How would you find the focal length by experiments? which method is the most accurate?

2. A gas flame is 36″ from a concave reflector; its image is clearly defined on a screen 50″ from the reflector. Find the focal length and the radius of the mirror.

3. In the following table fill in the vacant spaces:

u	v	f
30	50	
	50	10
100		20
20	20	

4. The radius of curvature of a concave mirror is 12″: a bright object is placed 18″ from the mirror; find the position of the image. Where will the image be when the object is 5″ from the mirror?

24. Caustics—Spherical Aberration.

If the surface be large, compared with the radius of curvature, the image is distorted. This is seen by looking into a bright tea-spoon. The light from a luminous body, instead of producing a single image, produces several; these together form a caustic. The caustic is well seen by allowing the sunlight to fall on the side of a basin, nearly filled with milk; the caustic is seen on the surface of the milk; or by allowing the rays to fall on a strip of bright steel (a clock spring) bent, and placed on white paper.

Every ray from a point L (fig. 117), instead of passing through the conjugate focus, cuts the next ray above the

Fig. 117.

focus; these intersections form the curve F M, above and below the axis. If the figure revolve on F L as an axis, the curve F M will describe the caustic surface. The caustic surface is in form, like the outside of a convolvulus.

To obviate spherical aberration, the aperture of the mirror must be small; if large, the outside margin should be covered with black paper. Such a covering is called a diaphragm, or a stop.

25. Real and Virtual Images.

When the rays of light actually pass through an image, so that the image can be received on a screen, and be examined by the eye or by a magnifying glass, the image is called a *real image*.

When the rays do not pass through the image, but only the continuations of the lines of their directions—that is, when the image has no real existence (it cannot be received on a screen) —the image is called a *virtual image*.

26. To Obtain, by Construction, the Positions of Images formed by Mirrors.

(*a*) See § 21, where the construction is explained, *when the object is beyond the centre.* The image is real, inverted, smaller than the object. By similar construction, viz.—

1. Draw from any point a ray parallel to the axis. This ray, after reflection, either passes through the (real) focus or appears to pass through the (virtual) focus.

2. Draw from the point a ray through the centre. This ray, after reflection, again passes through the centre.

3. Draw from the point a ray through the focus. This ray, after reflection, is parallel to the principal axis.

The intersection of two of these reflected rays, gives the position of the image.

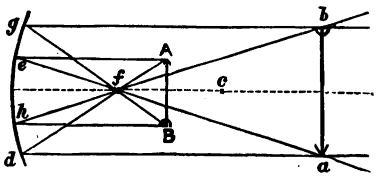


Fig. 118.

(*b*) *Object between the centre and the focus.*—The image *a b* is real, inverted, larger than the object A B, and beyond the centre (1 and 3 used, fig. 118).

(*c*) *Object between the focus and the mirror.*—The image *a b*, is erect, virtual, and larger than the object A B (1 and 2 used, fig. 119).

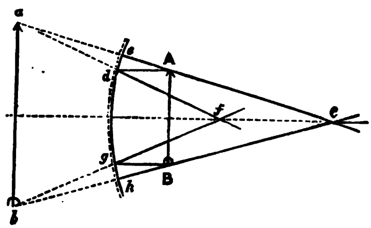


Fig. 119.

The rays *appear* to come from *a*, *b*. In the other cases, the rays actually passed through *a*, *b*, and the image was received on a screen; or by placing the eye about 10 inches away, so that the image was between the eye and the mirror, on removing the screen the image could be seen with the eye.

27. Size of Object and Image.

Half of the image and object are shown (fig. 120).

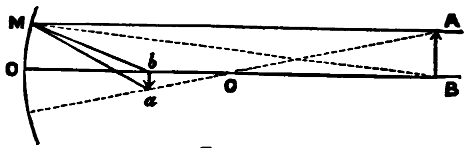


Fig. 120.

$$AB : ab :: BC : bC$$

The size of the image is to the size of the object, as their distances from the centre.

But $BC : bC :: BM : bM$

And if the aperture be small, $BM : bM :: BO : bO$

$\therefore AB : ab :: BO : bO$

The size of the image is to the size of the object as their distances from the mirror.

28. Arrangement of Results.

Combine the results of the last experiments. Suppose the object is at a great distance, and that it moves towards the mirror.

Position of		The image is			
Object	Image	Inverted or erect	Smaller or larger than the object	Real or virtual	Increasing in size or decreasing
1. Great distance	Focus	—	A point	—	*i*
2. Approaches centre, moves to right	Approaches centre, moves to left	*i*	Smaller	*r*	*i*
3. At centre	Centre	*i*	Equal	*r*	*i*
4. Approaches focus, moves to right	Moves rapidly to left	*i*	Larger	*r*	Increasing rapidly
5. Focus	At a very great distance	*i*	Much larger	*r*	*i*
6. Approaches mirror, moving to right	Seen behind the mirror	*e*	Larger	*v*	*d*

29. Convex Mirrors.

Blacken the inside of a watch glass, and use it as a convex mirror.

In no position can an image be obtained on a screen. The image can be seen 'in' the mirror. The image is in all cases virtual, upright, and smaller than the object.

The focus is *virtual*; parallel rays *appear*, after reflection, to come from a point behind the mirror.

The focal distance is equal to half the radius of curvature.

To Find the Position of the Image.

The ray A *e* from A (fig. 121), parallel to the axis, appears after reflection to come from *f*; the ray from A towards the centre

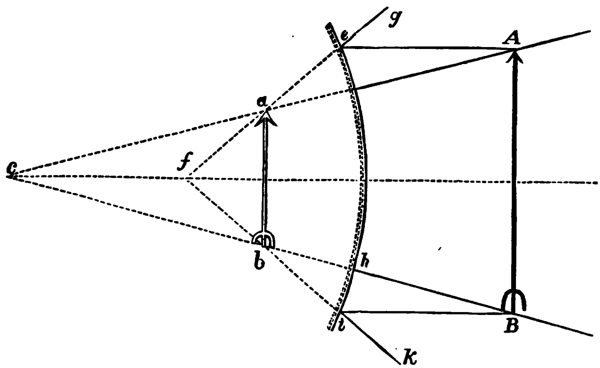


Fig. 121.

will be reflected along the radius and appear to come from *c*; the lines *c* A, *f e* intersect in *a*; *a* is the image of A, similarly *b* is the image of B. The points between A and B have their images between *a* and *b*.

The image is always formed behind the mirror; it is erect, virtual, and smaller than the object (fig. 122).

Distortion is produced in convex, as in concave mirrors, if the aperture be too great; the distortion is easily observed by looking at the back of a bright spoon.

The formula connecting the distances of the object (u), the *virtual* image (v), and the *virtual* focus (f) from the mirror is

$$\frac{1}{u} - \frac{1}{v} = -\frac{1}{f}.$$

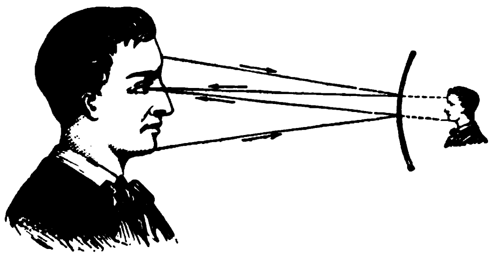


FIG. 122.

EXAMPLES. VII.

1. If the object in Example VI. No. 3 in each case be 6 inches long, calculate the length of the image.

2. Explain, and illustrate by a figure, the path of a beam of light from any source, which is reflected by a concave spherical mirror.

3. If you look at yourself in a convex spherical mirror you see an upright image. Under what circumstances can you see an upright image of yourself in a concave spherical mirror? What difference is there in respect to size between the images seen in the two mirrors?

4. A concave spherical mirror is so placed, that a candle flame is situated on its principal axis, and at a distance of 18 inches from its surface. An inverted image, three times as long as the candle flame itself, is seen sharply defined on the wall. What is the focal length of the mirror?

5. Explain, giving a drawing, how it is you see yourself as you do in a polished metal ball.

6. Describe, and explain the appearance of the caustic, formed when parallel rays are incident on a semicircular cylindrical mirror.

7. What is the difference between a 'real' and a 'virtual' image? Give a drawing, showing the formation of one of each kind.

8. Given a concave mirror whose focal length is 12 inches, where would you place a candle flame, in order that the image of it, formed by the mirror, may be (1) real, (2) virtual?

9. How would you practically determine the focal distance of a concave mirror?

CHAPTER IV.

REFRACTION OF LIGHT.

30. Refraction.

REMOVE one side from a square tin box, or any water-tight box, and insert a glass side; fasten with marine glue; allow the glue to harden.

Place the box (fig. 123, A), so that the light from the candle or lamp, striking over one edge, illuminates the opposite side. Fill the box with water; part of the bottom is now illuminated (B). The rays of light have changed their direction in passing from air to water; in both media the light is propagated in straight lines. The ray that enters the water is refracted.

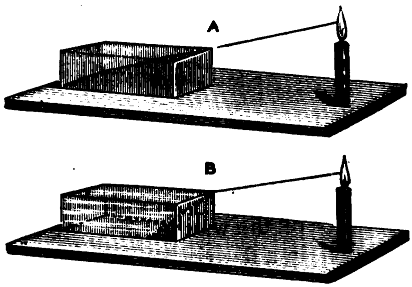


FIG. 123.

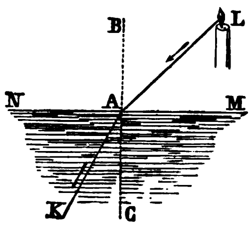


FIG. 124.

Meaning of Terms.

The ray L A (fig. 124) is called the incident ray, A K is the refracted ray, A B is the normal at the point A. The angle B A L is the angle of incidence, as before; the angle G A K

is the angle of refraction. In passing from air to water, the angle of incidence is greater than the angle of refraction.

31. Index of Refraction.

The laws of refraction, are easily demonstrated by the aid of the following piece of apparatus. This useful refraction trough is described in 'Light' by Mr. Lewis Wright.

A rectangular trough 16″ × 11″ × 2″; one end glass, the rest tin. One face has a circle 5″ radius cut out of the tin, its centre being 10″ from the bottom; in its place glass is substituted. A movable strip of tin 18″ × 2″, in which are cut 2 slits $1\frac{3}{4}'' \times \frac{1}{8}''$ at distance of 1″ and 9″ from one end. Blacken the tank and the strip. Paint on the circle the vertical and horizontal diameters; divide each quadrant into 9 equal parts (fig. 125).

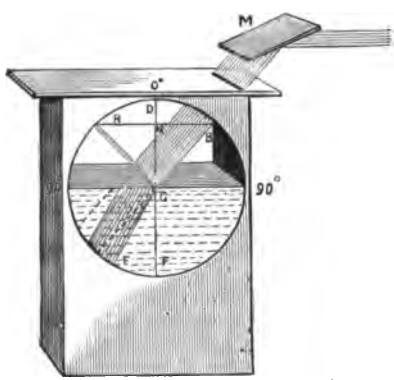


Fig. 125.

Reflect a beam from the mirror M, so that it passes through the slit in the strip of tin and enters the water at the centre of the circle. The path of the rays in air is made visible by a little smoke, and in the water by adding a few drops of milk. For large angles, place the strip along the glass end. Fill the trough with water to the horizontal diameter. Use sunlight or a parallel beam from the lantern.

The ray is bent at the surface of the water. Measure the angles of incidence and refraction, in a few cases.

Angle of incidence	BN	EF	Angle of refraction	$\frac{BN}{EF}$
60	4·3	3·2	40	1·34
50	3·8	2·9	35	1·33
40	3·2	2·4	29	1·33

No simple law seems to connect the two angles. Repeat the experiment, measuring the line B N, E F in inches and tenths of an inch in each experiment, and calculate the ratio $\frac{BN}{EF}$ in each case.

The results to two places of decimals are in the last column. The agreement in the results is very striking. Making allowance for errors of experiment, we can say that $\frac{BN}{EF}$ is a constant, whatever the angle of incidence may be.

$$BN \div EF = \frac{BN}{CB} \div \frac{EF}{CE}, \text{ because } CB = CE$$

$\frac{BN}{CB}$ is called the sine of the angle B C D

$\frac{EF}{CE}$ " " " E C F

$$\therefore \frac{BN}{EF} = \frac{\frac{BN}{CB}}{\frac{EF}{CE}} = \frac{\text{sine of the angle of incidence}}{\text{" " refraction}}.$$

Our experiments tell us, that in the case of light passing from air to water

$$\frac{\text{sine of the angle of incidence}}{\text{" " refraction}} = 1{\cdot}33, \text{ or nearly } \tfrac{4}{3}.$$

This number is called the INDEX OF REFRACTION. In a similar manner, the index of refraction has been found for various media.

From air to water	dex of refraction	$= \frac{4}{3}$
" glass	" "	$= \frac{3}{2}$
" carbon disulphide	" "	$= \frac{5}{3}$
" diamond	" "	$= \frac{5}{2}$

These numbers are approximate, and will vary somewhat with different specimens.

Not only was the *refracted ray* seen, but part of the light was *reflected* at the surface, according to the laws of reflection.

The incident ray = the reflected ray + the refracted ray. In examining this effect, cause the incident ray to make various angles with the normal; as the incident angle increases, the amount of light reflected increases.

THE LAWS OF REFRACTION (compare Reflection).

1. The incident ray, the refracted ray, and the normal are in the same plane.

2. The number obtained by dividing the sine of the angle of incidence, by the sine of the angle of refraction, is the same for the same media. This number is called the index of refraction.

32. SOME RESULTS OF REFRACTION.

A pond always appears shallower than it really is. Rays from L diverge (fig. 126), and after refraction reach the eye

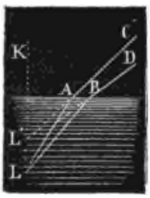


FIG. 126.

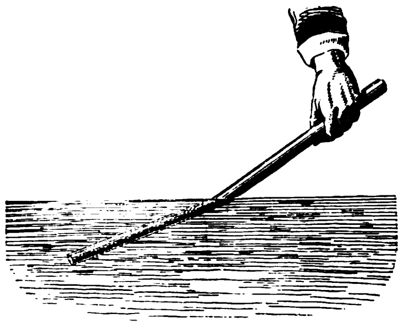


FIG. 127.

as the rays A C, B D. These appear to come from L'. That is, a point L, the bottom of a pond, or a fish, appears to be raised.

For the same reason, a stick partly under water, appears to be bent; the tip of the stick and every part under water appear raised (fig. 127). The ray is refracted as before.

Place a coin in an empty basin; move the basin so that you

are just unable to see the coin ; pour water in, and the coin becomes visible. The student can write out the explanation as an exercise.

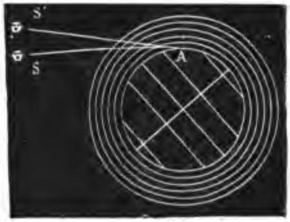


FIG. 128.

The atmosphere is less dense as we ascend ; we can suppose it to be made up of layers. The light from the sun or a star, instead of coming in straight lines, is refracted at every layer. Thus the light from S (fig. 128), reaches the eye as if it came from S′; that is, a star appears higher in the heavens than its real position. The sun is seen before it is above the horizon, and after it sets, for the same reason.

33. TO DRAW THE INCIDENT AND REFRACTED RAY.

In passing from air to glass, the index of refraction is $\frac{3}{2}$. Draw the incident and refracted ray, when the incident ray makes an angle of 60° with the normal.

Describe a circle. Make the angle T C I equal to 60°. Draw I T perpendicular to the normal. Divide I T into three equal parts. Make T S equal to two of the parts, draw S R parallel to the vertical diameter, join C R, draw R *t* parallel to the horizontal diameter.

I C is the incident, and C R is the refracted ray.

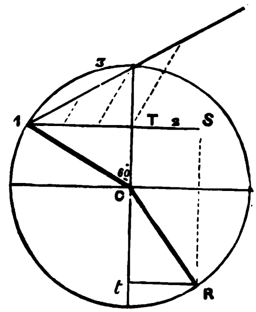


FIG. 129.

34. TOTAL REFLECTION—THE CRITICAL ANGLE.

Not only will light pass from air to water, but also from water to air, and we should expect the beam, after leaving the water, to be bent *from* the normal.

Arrange the apparatus of § 31. Place the strip against the end made of glass (fig. 125), so that light may enter through a slit in the

strip at the lowest possible point, and pass through the water to the centre of the circle. Use the reflector M near the base of the trough. The rays will be seen leaving the surface of the water, making a larger angle with the normal than the incident ray, and part of the ray will be reflected from the surface of the water. Let L A, A R (fig. 130) represent the path of such rays from water to air.

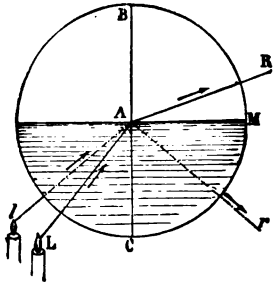


FIG. 130.

Make the angle with the normal greater; the ray emerges and takes a position nearer and nearer to the surface of the water; a certain angle is reached when the ray, after leaving the water, passes along the surface A M. This angle is called the CRITICAL ANGLE. When the ray makes with the normal, an angle greater than the critical angle, the ray *does not emerge; it is totally reflected*, as *l* A, A *r*.

In passing from water to air, the ray is bent away from the normal; when the incident ray in the water makes an angle greater than $48\frac{1}{2}°$, the ray is totally reflected.

When a ray passes from a denser medium to a rarer, the angle with the normal, at which the ray emerges parallel to the surface, is called the CRITICAL ANGLE.

[If we trace the ray from air to water, by the laws of refraction, we have $\frac{\text{sine of a right angle}}{\text{sine of the critical angle}} = \text{index of refraction}$. Sine of a right angle $= 1$. $\therefore$ sine of the critical angle $= 1 \div$ index of refraction; that is, the sine of the critical angle is the reciprocal of the index of refraction.]

The critical angle	from	water	to air is	$48\frac{1}{2}°$.
,,	,,	glass	,,	$40°$.
,,	,,	diamond	,,	$23°$.

Trace by construction rays from air to water when the incident ray makes 60° and 80°, with the normal; also from water to air, when the incident ray makes 30°, 40°, 50°, 60°, 70°, and 80° with the normal.

35. EXAMPLES OF TOTAL REFLECTION.

Place a coin in a glass of water; raise the glass, and look at the under surface of the water; the surface of the water looks like silver; all the light is reflected and the coin can be distinctly seen by reflection (fig. 131).

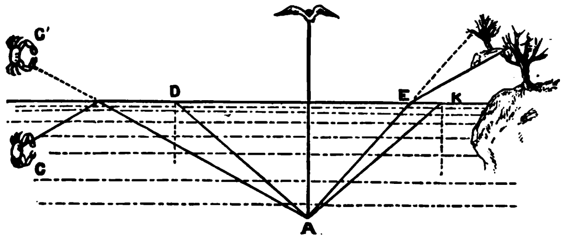


FIG. 131.

Suppose A to be a fish in water. All objects on shore will be seen in a cone, of which D K is the diameter, and A the apex; they will all appear raised. Beyond this circle, bodies in the pond will be seen by total reflection; C is seen as if at C′.

THE MIRAGE.—In hot countries, the layer of air nearest the earth is heated most; it is thus less dense.

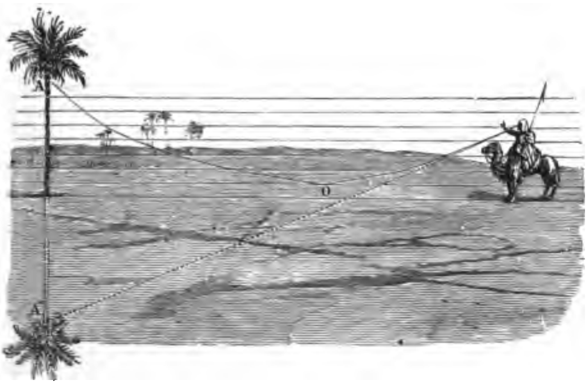


FIG. 132.

Light from A (fig. 132) is refracted *from* the normal; the refraction is increased as it passes to different layers; at O it

is totally reflected, having reached the critical angle; it is then refracted in the various layers. The traveller sees the tree in the direction the light last reaches his eye; it appears at A′.

The quivering of objects seen over coke ovens and iron-works is due to unequal refraction.

Examples. VIII.

1. Explain clearly what you mean by the statement that the refractive index of water is 1·333. How do you account for the appearance presented by a stick held in an oblique position, partly immersed in water, to a person looking at it sideways?

2. If you hold a glass of water with a spoon in it, a little above the level of the eye, and look upwards at the under surface of the water, you will find that you are unable to see that part of the spoon above the water. Explain this.

3. Using the indices of refraction in § 31, find by construction and measurement the critical angle in each case.

4. Explain why a fish seen in a pond, or in an aquarium tank, appears to be nearer the observer than it really is. Draw a picture to illustrate your answer.

36. Refraction through a Thick Plate.

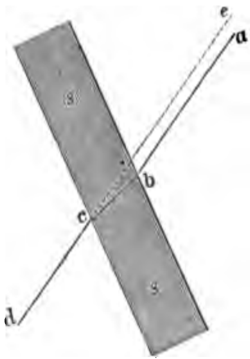


Fig. 133.

Hold a piece of thick glass obliquely, and look at an object, such as a post or window, so that part is seen through the glass, and part by direct vision. The object seems broken at the edge of the glass.

Let *ab* be a ray of light incident on a thick glass plate *s s* at *b* (fig. 133); the ray is refracted to *c*, and, again, on leaving the glass in the direction *c d*; *c d* is parallel to *a b*; the ray has moved to the left; an observer sees *a*, in the direction *d c*, if the ray pass through the plate, whereas if the plate be absent he sees it in the direction *b a*.

Multiple Images are Formed by Refraction and Reflection, by Mirrors made of Glass.

The ray from A (fig. 134), meets the glass at *b*, is reflected, and the eye sees the image at *a*. Part of the ray enters the glass, is refracted to *c*, the metallic surface; it is there reflected to *d*; at *d* it is refracted to H; the eye sees the image (the brightest image) at *a'*; the ray *cd* is further reflected at *d*, and produces other images less distinct.

These multiple images can be seen by placing a candle close to a mirror.

Fig. 134.

Incident Light=Reflected Light (Regular and Irregular)+Transmitted Light+Absorbed Light.

A ray of light, A B, meets a transparent body such as glass; the incident ray divides into the refracted ray B D, and a reflected ray B C; the ray B D is partly reflected as D *b*, and partly refracted as D F; this is repeated. The emergent rays D F, *df*, together with the reflected rays B C, *bc*, do not, however, make up the whole of the incident ray A B. Part of the light is absorbed by the glass, and part is lost by irregular reflection.

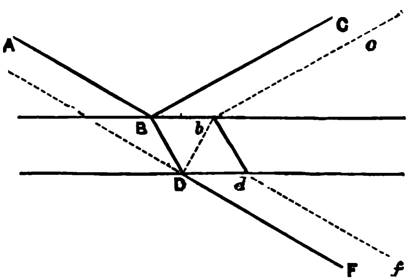


Fig. 135.

Original amount of light=reflected light (B C, *bc* . . .)
+transmitted light (D F, *df* . . .)+absorbed light.

In polished reflectors, unless the metals are very thin, no part is transmitted, very little is absorbed. They are in the latter respect superior to silvered glass.

37. Illustrations.

As the angle of incidence increases, we have seen that the reflecting power of water increases, while the refracting power decreases.

When glass is pounded into small particles it appears white, like salt; the light is reflected from the various pieces in all directions; thus an amount of crushed glass, which is illuminated by a spot of sunlight coming through a hole in the shutter, is seen in all parts of the room (a perfectly polished piece of glass would only be seen at one point), but the light is so broken up by repeated reflections, that it is unable to pierce beyond a very small depth, and if the layer be at all thick no light is transmitted.

This can be easily understood. A ray after passing through a plate of glass is enfeebled; part has been reflected, part absorbed. If the same thickness be divided into thin plates with air between them, we increase the surfaces where reflection takes place; therefore less is transmitted; by increasing the number of plates, the glass can be made opaque, but more light will be reflected. When glass is pounded this takes place; of course the particles are not in parallel plates.

If we run in between the plates, a mixture that has the same refractive index as glass, then the various plates act like one piece of thick glass, the reflecting power is diminished, and light can be transmitted.

This explains why paper becomes transparent, when oil is added to it. Clouds appear black when the light has undergone reflection, and therefore but little light has been transmitted.

Examples. IX.

1. You have a piece of thick plate glass, through which you look at a vertical pole (say, a telegraph pole). The glass being held so that part of the pole is seen directly, and part through the glass, describe and explain the change in the apparent position of the part of the pole which is seen through the glass, when the latter is turned about a vertical axis.

2. A thick plate of glass is interposed obliquely between a candle and the observer's eye. Will the apparent position of the candle be altered by the glass? Draw a picture illustrating your answer.

3. An object is seen by looking through a thick plate of glass with parallel surfaces; how will the position and character of its image be altered by turning the glass obliquely? Illustrate the effect by a figure.

4. Explain the images of a candle that are seen when a thick glass mirror is used; would they be seen in a polished silver reflector?

5. Account for the transparency of paper which has been soaked in oil.

6. A piece of colourless mineral is dropped into a colourless liquid; the mineral is invisible in the liquid. How are the refractive indices of the liquid and the mineral related?

CHAPTER V.

PRISMS AND LENSES.

38. Refraction through a Prism.

Take one of the prisms and observe any object through it. The most striking thing is the colour introduced. Disregarding the colour, observe the position of the image.

Holding the prism in the position of fig. 136, the candle seems tilted towards the apex of the triangle. The ray from the object *d* is refracted at the edge *a b*, and again at *a c*, according to the laws of refraction; the eye sees the image at *l*.

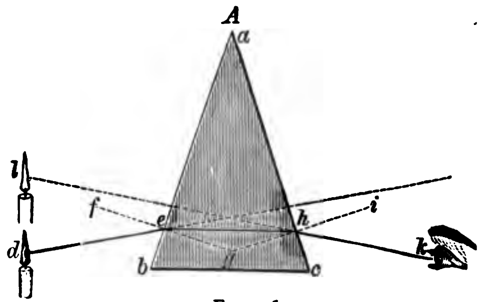


Fig. 136.

a b, *a c*, represent the refracting surfaces of the prism. The line where these surfaces meet (seen in elevation as *a*), is the refracting edge. The angle *b a c* is the refracting angle. The angle *d o l*—that is, the angle between the incident ray *d e*, and the refracted ray *k h* produced—is called the angle of deviation.

Make a small hole in the centre of a sheet of blackened cardboard. Place a candle in front of the cardboard, the wick being

the same height from the ground as the hole. Receive the spot of light (*a*) on a screen (fig. 137). Behind the hole place a prism with the refracting edge horizontal and parallel to the screen. The spot of light is moved (*b*), and by joining these two positions with the hole, the angle of deviation is practically found.

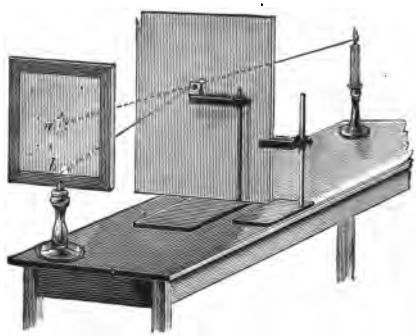


FIG. 137.

Move the prism on the refracting edge as an axis; a position will be found in which the angle of deviation is the smallest possible. This is called the angle of *minimum deviation* for the prism. It takes place when the refracted ray is parallel to the base of the prism, or when the angle $khc =$ the angle deb (fig. 136).

Draw a prism with a refracting angle of 40°, 50°, or 60°. Trace by construction a ray through the prism, allowing the ray to meet the surface at different angles.

It will be found that the deviation is on the whole towards the base of the prism. The construction will also show, that as the angle of the prism increases the deviation increases. Verify by experiments.

Fill the divisions of the divided glass cell with different liquids: (*a*) water, (*b*) turpentine, (*c*) alcohol, (*d*) carbon disulphide. Send a beam from a horizontal slit through the four divisions.

The refraction is least in the water cell, and greatest in the carbon disulphide cell, the others being intermediate; therefore the deviation depends also upon the refracting medium.

Use a glass prism, whose angle is a right angle or greater than a right angle; in no position is the beam able to get through.

In fig. 138 the angle *b c n* is greater than the critical angle of glass; the beam *b c* is therefore totally reflected at *c* as *c d*, and does not emerge at the face A C.

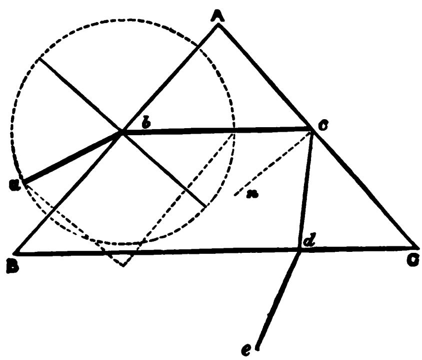


Fig. 138.

The angle of the prism, must not be greater than twice the critical angle of the substance, if a ray is to emerge.

The critical angle for glass is 42°; the refracting angle of a glass prism must not exceed 84°.

The Index of Refraction.

When a solid is made into a prism, its index of refraction can be found, by measuring the angle of the prism (a), and the angle of minimum deviation (d).

$$\text{The index of refraction} = \frac{\text{sine } \frac{1}{2}(a+d)}{\text{sine } \frac{1}{2}a}.$$

The index of refraction of liquids, can be found by enclosing them in prisms, whose refracting surfaces are glass plates with parallel surfaces. The parallel glass plates will not affect the deviation (§ 36), which will depend on the liquid alone.

39. The Right-angled Prism as a Reflector.

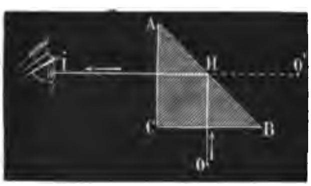


Fig. 139.

A ray from a luminous point O, enters the face C B of the isosceles right-angled prism perpendicularly in the surface (fig. 139); it is therefore not refracted at that surface; it meets the surface A B at H, making an angle of 45° with the normal at H; it

is therefore totally reflected, and emerges as the ray H I. An eye sees the image at O′.

A B forms an excellent reflecting surface, and has the advantage over a metal reflector in that it does not tarnish. Use the right-angled prism as a reflector.

EXAMPLES. X.

1. Trace the path of a beam of parallel rays of light which enters a right-angled glass prism, in a direction perpendicular to one of its three faces.

2. Show how the hypotenuse face of a right-angled prism may be used as a reflector. Explain the connection between the refractive index of a medium and the angle at which a ray is totally reflected.

3. A ray of light is incident perpendicularly upon one of the two faces of a right-angled isosceles prism which bound the right angle. Draw a picture showing the subsequent path of the ray, and explain your construction.

4. The angles of a glass prism are 90°, 70°, and 20°, and a ray of light enters the prism normally at the face bounded by the angles 90° and 70°. If the critical angle for glass be 41°, determine (by construction) after how many internal reflections the ray will emerge.

40. A LENS ACTS LIKE A NUMBER OF PRISMS.

Suppose we have a number of small prisms, and we place the prism *b* with the largest angle, so that a spot of light *a* is refracted to *c*. Join *a c*. Then evidently if a prism *h*, exactly like *b*, be placed as in the figure, it also will refract the light to *c*.

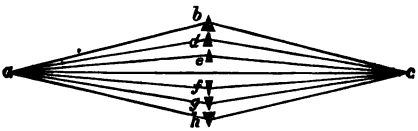


FIG. 140.

By using *d* and *g* with smaller angles (less deviation) we can by trial find positions, so that they also refract to *c*. Similarly *e* and *f*; finally between *e* and *f* we might place a plate of glass with parallel sides. Thus a number of rays from *a* can be made to converge to *c*.

The deviation does not depend upon the distance apart of the refracting surfaces, but upon the inclination of the surfaces.

B (fig. 141) will have exactly the same effect as A, if the surfaces of *a*, *b*, *c*, . . . in B, be inclined at the same angle as the surfaces of *a*, *b*, *c*, . . . in A.

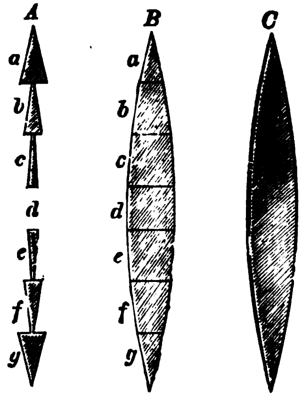


FIG. 141.

41. NATURE OF A LENS.

If we had a very large number of such prisms fitted together as in B, the joinings would appear smooth and a prism whose section is C would be formed.

We have simply taken the rays in the plane of the paper, but the rays and prisms would be in all directions. C is merely a section.

A body like C, *when made of a refracting substance, is called a* LENS, *and it may be considered as being made up of a large number of prisms.*

It is found that lenses whose surfaces are parts of the surface of a sphere, *if the surfaces be small compared with the whole surface of the sphere*, act like the prisms in fig. 140.

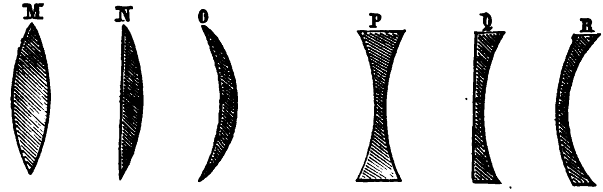


FIG. 142.

The names given to lenses are (fig. 142) :—

(M) Double convex—both surfaces convex.

(N) Plano-convex—one surface convex, one plane.

(O) Concavo-convex converging—one surface convex, one concave.

(P) Double concave—both surfaces concave.

(Q) Plano-concave—one concave, one plane.
(R) Concavo-convex diverging—one concave, one convex.
O and R are also called meniscus lenses.

The first three are thickest at the middle, and are called *converging lenses*—that is, rays of light, after being refracted, converge. The last three are thinnest in the middle, and are *diverging lenses*; rays of light, after passing through them, diverge.

42. Surfaces of Lenses are usually Parts of Spheres of Equal Radii.

Fig. 143 shows how a double convex lens is formed; the student should construct figures for the other five lenses.

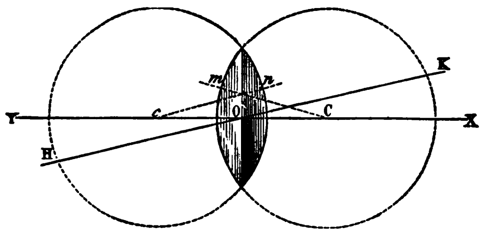


Fig. 143.

The line Y X passing through the centres, is called the principal axis. *c n*, C *m* will be as before the normals at *n m*. C, *c* are the centres of curvature. O is the optical centre.

As in mirrors, the point where parallel rays come to a focus, is called the principal focus.

Use the lenses: hold them so that the sunlight (parallel rays) falls upon them; find the focus on a piece of metal; measure the distance from the lens to the focus. This is the focal distance.

With M, N, O a focus is found. Converging lenses.
„ P, Q, R no focus „ Diverging lenses.

Use also the light of a distant flame (the rays are practically parallel), and measure the focal length.

Conversely, if a luminous point be placed at the principal focus, the rays of light, after passing through the lens, should be parallel.

Verify this by fixing the lens on a stand, placing a screen with a small hole at its focal distance; behind this place a lamp, on the other side of the screen; catch the rays of light on another screen at any distance. The surface illuminated should be the same size in any position.

This explains the method of obtaining a parallel beam from diverging rays. A converging lens is placed, so that the source of light is at its focus.

Protect the side of lens nearest to the lamp with a *diaphragm*, so that only a small portion of the surface is used.

43. To Find the Relation between the Distances of the Image and the Object from a Lens.

Arrange the candle or gas at various distances from the lens; obtain on the screen the image. Measure the distances of image and object from the lens (fig. 144).

Place the eye so that the image on the screen is between

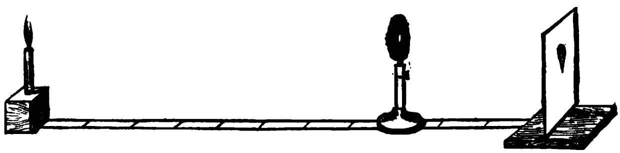


Fig. 144.

the eye and the lens, and is about 10 inches away. Remove the screen; the image can still be seen. Take another convex lens and magnify the image on the screen. Move away the screen; the image can still be magnified. The image is *real*.

EXAMPLE.

A double convex lens, focal length $11\frac{1}{4}$ inches (found as in § 42).

Distance from lens				(5) Value of $\frac{1}{u}+\frac{1}{v}=\frac{1}{f}$	(6) Average value of f calculated
(1) of object u	(2) $\frac{1}{u}$	(3) of image v	(4) $\frac{1}{v}$		
21·5	·046	24	·042	·088	
20	·050	28	·036	·089	11·3
15	·067	45	·022	·089	

Columns 1 and 3 are measurements; 2 and 4 are calculated from 1 and 3; 5 is calculated from 2 and 4; 6 is calculated from 5.

We conclude that in a double convex lens (and by a similar method it can be shown to be true for all converging lenses)—

The sum of the reciprocal of the distances of the object, and the reciprocal of the distance of the image, from the lens, is equal to the reciprocal of the focal length.

This is true for all converging lenses, and we can thus use it to find the focal length of a lens. The positions of the image and the object are convertible; when the object is a luminous point, these positions are called the conjugate foci of the lens.

$$\frac{1}{u}+\frac{1}{v}=\frac{1}{f}$$

If $u=v$ then $\frac{1}{f}=\frac{2}{u}$. $\therefore f=\frac{u}{2}=\frac{u+v}{4}$

$\therefore$ to find the focal distance of a lens, arrange so that the image and the object, are both the same distance from the lens. The fourth of the distance between the image and the object is the focal length.

NOTE.—In using a candle there is a little difficulty in determining when the best image is obtained. The lens should be covered on one side with black paper, so as to leave only a small aperture, otherwise the image will be coloured and distorted. Just before deciding the position of the image, push the wick out of the flame; the image of the glowing wick can be obtained with great distinctness.

44. To Obtain the Position of the Image by Construction—Convex Lenses.

The following experimental results are used:—

a. Rays parallel to the axis, after refraction pass through the focus (§ 42).

b. Rays that pass through the optical centre do not undergo refraction. In fig. 141 the part d is a glass plate with parallel sides; a ray in passing through such a plate is slightly refracted (see fig. 133); its direction is parallel to the original direction. If the lens be not very thick, and the rays be nearly perpendicular to the surface, we can neglect this small displacement.

1. *The object is twice the focal distance from the lens* (fig. 145).

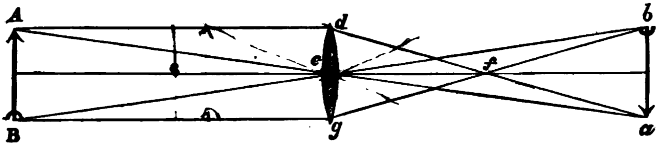


Fig. 145.

The ray Ad by (a) passes through focus f, the ray Ae by (b) is not refracted; these rays meet in a. a is the image of A. Similarly b is the image of B. If the surface of the lens, *be small compared with the surface of the sphere*, all rays from A and B will pass through a and b.

The image is real, inverted, and is the same size as the object.

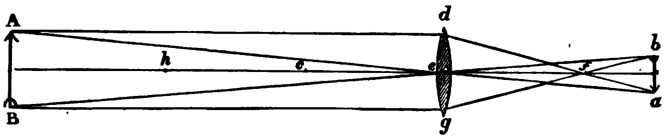


Fig. 146.

2. *The object is at a greater distance than twice the focal distance* (fig. 146).

Use the same construction. The image is real, inverted,

and smaller than the object; it is moving towards the focus, and is diminishing in size.

3. *The object is at a distance less than twice the focal distance* (fig. 147).

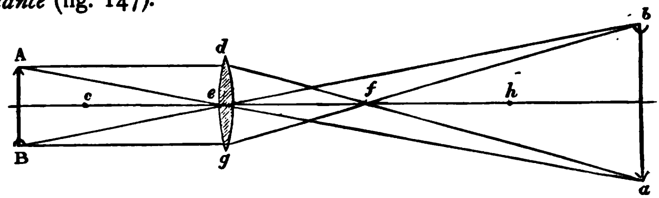


FIG. 147.

The image is real, inverted, at a greater distance away; it is increasing in size.

4. *The object is between the focus and the lens* (fig. 148).

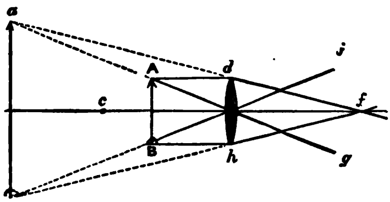


FIG. 148.

The image is virtual, erect, and greater than the object.

The image being virtual the formula of § 43 becomes

$$\frac{1}{u} - \frac{1}{v} = \frac{1}{f}.$$

Compare the formulæ for convex lenses with those for concave mirrors.

CONCAVE LENSES.

These may be considered to be composed of prisms, whose refracting edges are turned towards the centre of the lens.

Light, then, is refracted from the axis of the lens; diverging rays will be the result.

With a concave lens no real image can be obtained.

The formation of the image by construction, is the same as with the convex lens.

The ray A *c*, parallel to the axis, is refracted, and *appears* to come from the virtual focus *f*.

The ray A *e* through the centre, continues in the direction A *e*. Both *appear* to come from *a*.

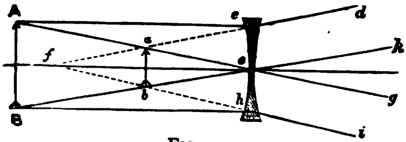


FIG. 149.

a is the image of A; similarly *b* is the image of B.

The image is always virtual and erect.

The formula connecting the distance of the image, the object, and the focus in concave lenses from the centre of the lens, can be deduced from $\frac{1}{u}+\frac{1}{v}=\frac{1}{f}$ by remembering that in a concave lens, the focus and the image are both virtual.

The formula becomes $\frac{1}{u}-\frac{1}{v}=-\frac{1}{f}$. Compare it with the formula for a convex mirror.

45. RELATIVE SIZE OF IMAGE AND OBJECT.

By examining any of the figures for lenses, it is seen that by similar triangles

The size of the object is to the size of the image, as the distance of the object from the centre of the lens, is to the distance of the image from the centre of the lens.

EXAMPLES. XI.

1. Show how to find the position, and magnitude, of the image of an object, placed at a given distance from a convex lens of given focal length. An arrow 5 inches long is placed 8 inches in front of a convex lens, whose focal length is 3 inches; find the length of the image.

2. A convex lens of $4\frac{1}{2}$ inches focal length is held at a distance of 3 inches from a disc half an inch in diameter; find the position and size of the image of disc.

3. Explain the way in which a double convex lens is employed to obtain a magnified image of an object.

4. On a sheet of paper placed vertically is written a capital L. If an observer stand 3 feet in front of the paper, and hold a double convex lens, of 6 inches focal length, half-way between his eye and the paper, he will see an image of the letter. Draw a picture of the image as seen, and state whether it is larger or smaller than the object.

5. State generally the effect of a lens upon a ray of light passing through it. Show how with a double convex lens, an image of a lighted candle may be seen (1) inverted and magnified, (2) inverted and diminished, (3) erect and magnified.

6. A convex lens of 6 inches focal length is employed to read the graduations of a scale, and is held so as to magnify them three times. Find how far it is held from the scale.

7. A luminous object moves along the axis of a double concave lens. Trace the position and size of the virtual image.

8. Describe a method of determining the focal length of a convex lens. Explain the relation between the effects produced by a convex lens and a concave mirror of the same focal length.

9. Explain the formation of the image of an object by means of a concave spherical mirror. Compare a convex spherical lens with a concave spherical mirror of the same focal length, as regards its action on a beam of light.

10. Find the relation between the positions of the conjugate geometrical foci for a concave cylindrical mirror, and explain how to make use of this relation to find the curvature of the mirror.

CHAPTER VI.

OPTICAL INSTRUMENTS.

46. The Camera—The Magic Lantern

The photographic camera is merely the pinhole camera of § 8, with a convex lens instead of the pinhole, and roughened glass instead of the tissue paper. By moving the position of the lens, an inverted real image is obtained upon the glass; if the whole be enclosed, so that light enters by the lens alone, and a properly prepared sheet be placed in the position of the roughened glass, the image can be printed upon this prepared substance.

In a magic lantern, an inverted transparent figure on glass, is placed at a distance a little beyond the principal focus of a convex lens; if this figure be *strongly illuminated*, an erect magnified real image is obtained on a screen at a considerable distance from the lens. To attain the proper illumination, a large convex lens (a condenser) is used to condense the rays from a powerful lamp upon the glass; and in order that as many rays as possible may be utilised, a spherical reflector is placed behind the lamp.

47. Distinct Vision—Microscopes.

We see objects best when they are at a distance of from 10 to 11 inches from the eye; this is called the distance of distinct vision; it varies in different persons. The eye must be placed at this distance from an image to see it distinctly.

The Simple Microscope is a double convex lens of short focal length. The eye is placed close to the lens and the

object A B is placed at a distance less than the focal distance (fig. 150); the image, therefore, is virtual (§ 44, No. 4), erect,

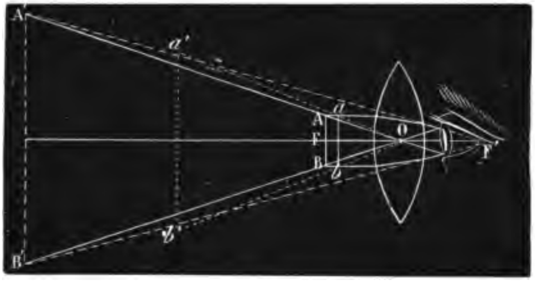


FIG. 150.

and enlarged. The nearer the object is to the focus the larger the image. The lens is moved until the distance of the image is at the distance of distinct vision; this varies in different persons, and the lens is *focussed* to suit them. If the object be at A B, the image is at A′ B′; if at *a b*, the image is *a′ b′*.

To see A B distinctly without the aid of a lens, it would be necessary to place it the same distance away as A′ B′; that is, at the

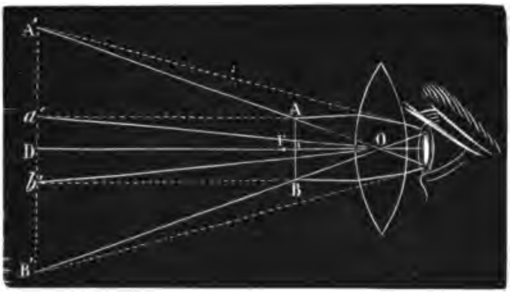


FIG. 151.

distance of distinct image. Drawing A *a′*, B *a′* parallel to the axis (fig. 151), we see that the effect is to increase the size in the ratio

$$\frac{A' B'}{a' b'} = \frac{A' B'}{A B} = \frac{D O}{C O} = \frac{\text{limit of distinct vision}}{\text{distance of the object}}.$$

C O is nearly equal to the focal length ;

∴ roughly, the magnification is the ratio between the distance of distinct vision and the focal length. This supposes that the eye is at the optical centre O.

More exactly $\frac{1}{DO} - \frac{1}{CO} = -\frac{1}{f}$ (§ 44), $\therefore \frac{DO}{CO} = 1 + \frac{DO}{f}$.

This use of a convex lens, for producing an enlarged, ***virtual***, and erect image, should be compared with its use, when an inverted, real image is produced.

The Compound Microscope.

In § 44 we have already examined a real image by means of a lens.

M (fig. 152), is a lens of small focal length ; an object A B is placed just beyond its focus ; a real, inverted image ***a b*** of A B is obtained

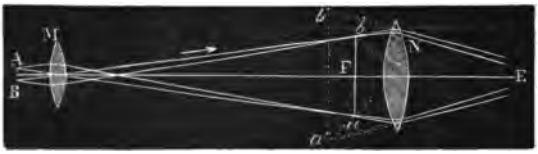


Fig. 152.

A lens N of greater focal length is used to examine the image ; N is so placed that the real image ***a b*** is between the focus F and the lens ; therefore, an upright virtual image ***a' b'*** is obtained. This is at the limit of distinct vision from N.

M is the object glass ; N the eye piece. Both are surrounded with blackened tubes, and both can be moved so as to occupy the best positions. The object A B must be strongly illuminated.

48. The Astronomical Telescope.

Revert to the experiments in § 44.

Fasten the large lens to a light temporary bench ; take it in the hand and point it to a distant object. If at night, move the

candle as far away as possible. An inverted, real, diminished image is obtained on the screen.

Magnify the image by placing a convex lens of small focal length on the bench, using it as a simple microscope; then remove the screen; the small lens magnifies the image, producing, compared with the image, an upright, virtual, enlarged image. Surround both lenses with blackened tubes, and an ordinary astronomical telescope is formed; the tubes slide one within the other for adjustment.

a b is an object at a great distance; *c d* is the refractor, with its focus at f_1; the image, real, inverted, is formed at a_1b_1. The eye piece *e g* magnifies (see simple microscope) the real image a_1b_1. The eye sees the virtual image, a_2b_2, inverted, as compared with *a b*. Practically, *a b* being at a great distance,

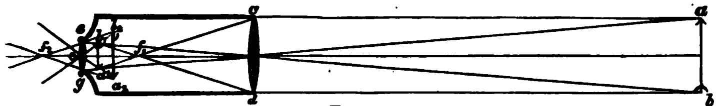


FIG. 153.

a_1b_1 is formed at the focus f_1. In examining celestial bodies the inversion causes no inconvenience.

The magnification is nearly

$$\frac{\text{focal length of object glass}}{\text{,, \quad ,, \quad eye piece}}.$$

If *e g* be moved, so that a_1b_1 is at a greater distance from *e g* than its focal distance, a real inverted image of the image a_1b_1 will be formed on the other side of *e g*; that is, the second image will be erect compared with the object *a b*. This second, real, erect image can, as in fig. 153, be examined by another lens similar to *e g*; the result is an erect virtual image. With proper tubes, a simple TERRESTRIAL TELESCOPE is formed. In practice, two similar convex lenses, are so arranged between the the first image a_1b_1 and the eye piece *e g*, that they produce a second, real, erect image of *a b*; this image is magnified by *e g*.

49. THE GALILEAN TELESCOPE—SINGLE OPERA-GLASS.

Instead of using a convex lens to examine the real image in fig. 144, use a concave lens; begin in the position in which the

convex lens was placed and move up to the screen; no image is obtained. Remove the screen and move the concave lens gradually towards the large lens; at length the candle or object is seen, but it is ERECT. Refer to § 44 concerning concave lenses.

If the large lens and concave lens be surrounded with proper tubes, the Galilean Telescope is formed, and on a smaller scale the opera glass.

c d is the refractor or object glass, *e g* the eye piece; the object *a b* would form a real image a_1b_1, but the rays meet the concave lens *e g*, whose focus is f_2. Thus the rays which were

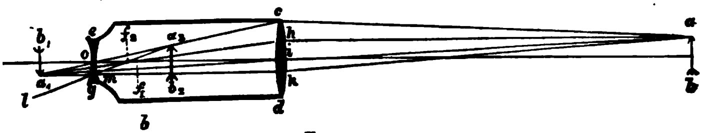


FIG. 154.

converging to a_1, appear after refraction as if they came from a_2. An erect image of the object *a b* is obtained; *a b* being at a great distance, a_1b_1 would practically be at the focus of *c d*.

$$\text{The magnification is } \frac{\text{focal length of object glass}}{\text{,, \quad ,, \quad eye piece}}$$

EXAMPLES. XII.

1. What is the relation between the magnifying power of a compound microscope and the focal lengths of the lenses employed in it?

2. Trace a pencil of rays from an object through one of the sides of an opera glass, and explain the action of the lenses on it.

3. Sketch and describe a magic lantern showing the effect of the lens.

4. Describe the astronomical refracting telescope. If it is adapted so that rays coming from a distant object shall form a parallel pencil after passing through the telescope, what change must be made in order that an object may be seen distinctly by means of it?

5. Explain the different effects produced by a convex lens when it is used (1) as the object glass of a telescope, (2) as a magnifying glass.

CHAPTER VII.

COLOUR.

50. Analysis of Light—Spectrum.

In using the prism, colour was introduced into the images; in experimenting with a large lens colour also appeared. The colour seemed due to refraction.

Use either sunlight passing through a hole in the shutter, or remove the objectives from the lantern; cover the opening with a cap in which a small hole is cut, and with a large lens focus the hole on the screen. A circular spot of light is obtained. Place the prism in the path of the beam; the circle spreads out into a band of colour. This band is called a *spectrum*. The name *dispersion* is given to this separation. Some colours are refracted more than others. The order of the colours is red, orange, yellow, green, blue, indigo, violet; red is refracted least, violet most. We found that certain liquids, especially carbon disulphide, refracted light more than glass. A carbon disulphide prism is therefore frequently used instead of a glass prism; greater dispersion is thereby obtained.

Instead of a hole, use a slit $1\frac{1}{2} \times \frac{1}{16}$ (see fig. 155), cut in blackened paper, and forming the front of a cap, that slips on the lantern; focus the slit S on the screen A B by means of the lens M. Interpose the carbon disulphide prism R P Q, and the spectrum A′ B′ is obtained. Protect the convex lens by a square of blackened cardboard, to prevent stray light from reaching the screen; a square of white cardboard forms a convenient screen.

Having received the colours on a sheet of cardboard, place the eye in the band of colour and move it; in different positions the slit is seen coloured differently: the spectrum is made up of a large number of coloured images on the slit. Cut a

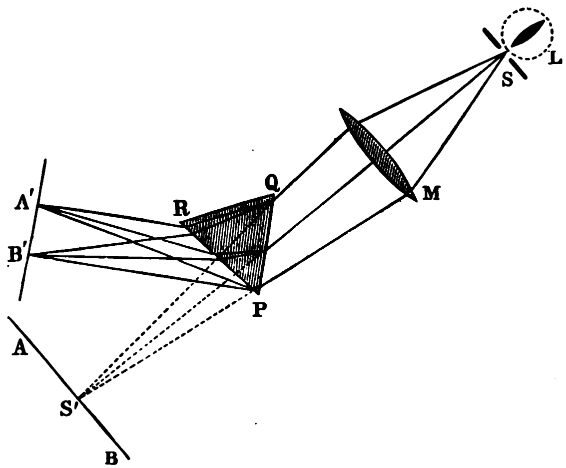


FIG. 155.

fine slit in the screen and allow, say, the green light to pass through; use another prism and refract the green rays: there is no further breaking up of colour. The colours are simple colours.

51. SYNTHESIS OF WHITE LIGHT.

If white light be made up of the foregoing colours, by mixing these colours white light should be produced.

FIG. 156.

1st Method.—Arrange a prism to obtain a spectrum. Place a similar prism near the former so that their faces are parallel, as in fig. 156. The light, on emerging from the second prism, is no longer coloured. Slip a card between them; notice the small spectrum on the card; place the

card so that it stops part of the light. The light stopped is coloured. The image on the screen is coloured.

2nd Method.—Let the spectrum fall upon the concave lens. At its focus, where all the coloured rays mix, a white image is obtained. Cut off some of the rays with a card before they pass through the lens—say at the red end of the spectrum. The image at the focus is blue.

3rd Method.—Fill a tall confectioner's jar with clear water. Let a vertical beam, after passing through the prism, fall upon the jar. The rays converge after being refracted by the jar; the image on the other side is white. Interpose a card between the prism and the jar. Notice the colour stopped by the card, and the result on the image. Stop the blue end; red appears on the screen.

4th Method.—Divide a disc of cardboard into fourteen equal parts. Beginning with red, paint the sectors with brilliant colours in the following order: red, orange, yellow, green, light blue, dark blue, purple. Paint a black ring round the coloured sectors, and also a black circle at the centre. Fasten this colour disc to a whirling table or top (see Appendix) and turn. The colours blend and white is produced.

Fasten sectors of white paper over any colour. On turning, distinct colour appears: cover up the red and orange; a blue tint appears. Cover up the blue and purple; a red tint appears. Newton concluded that

White light is made up of seven colours, each colour having a different refrangibility.

52. Colour of Bodies.

Violet is refracted more than blue, blue than yellow; red is refracted least of all.

The division into seven colours is arbitrary; there is in reality an enormous number, one colour passing into another. By abstracting any of the components, as was done in the previous experiments by stopping certain rays, the balance is disturbed and colour results.

Colour is the result of suppressing colour.

Place coloured objects in the spectrum; move a bright red

ribbon along it. The red is deepened in the red end; at the blue end it appears black—that is, colour is absent. Similarly a deep blue ribbon appears black at the red end.

53. Reflected, Absorbed, Transmitted Colours.

We learn that colour does not depend upon the body but upon the kind of light that falls upon it.

Cover the slit of the lantern with a red glass; the blue end of the spectrum is extinguished. Try a blue glass; the red end is extinguished. A yellow glass allows yellow and part of the green and orange to pass. Use both red and blue; no light passes. Use blue and yellow; a little of the green is seen. The red glass absorbs blue light and allows only red to pass. The blue absorbs red light and allows only blue to pass.

Collecting our facts, we find that bodies absorb, transmit, and reflect light; that bodies reflect the light they transmit, and conversely. A red coat is red because it absorbs all the colours save the red; this it reflects. The speedwell is blue because it absorbs all the red and reflects the blue. Red glass is red when held to the light because it absorbs all the blue and only allows the red rays to pass through.

If these conclusions be correct, then if light, instead of being composite, were homogeneous, variety in colour would be non-existent. This can be tested by holding platinum wire dipped in common salt in the flame of the Bunsen burner; if no other light be in the room, the intense yellow flame only supplies yellow light; bright red, blue, etc., will appear black; everything in the room is in a shade of yellow or is black.

54. Complementary Colours.

It is found that, by properly selecting two colours and blending them, white is produced. Any two colours that make white light when combined, are called complementary colours; red and blue, yellow and blue, are complementary colours.

The common experience is that yellow and blue make

green, but a mixture of pigments is different from a mixture of colours. Cover the slit with a solution of copper sulphate in the cell ; the blue and part of the green rays pass and appear on the screen : on using a solution of picric acid (yellow) the yellow rays and part of the green rays pass.

When blue and yellow paints are mixed, the blue absorbs all save the blue and green; these it reflects. The yellow absorbs all except yellow and green. But the blue absorbs the yellow and the yellow absorbs the blue; the only part reflected is the green : we then call the mixture green.

55. Chromatic Aberration.

The violet rays are refracted more than the red. When light passes through a lens there will be a focus for each of the coloured rays.

Use the large lens and the candle, as in § 43 ; remove the black diaphragm ; receive the image on the screen ; as the screen approaches the lens from a distance, the edge of the image is coloured red, bordered with violet on the outside (fig. 157). At a certain point a fair image in which red predominates

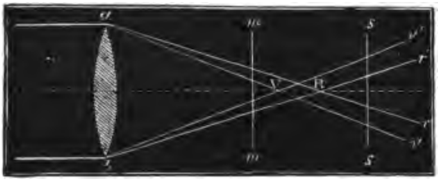


Fig. 157.

is produced, violet being on the outside. Nearer the lens the violet predominates ; the violet is in the centre, the red on the outside.

This is called chromatic aberration. *a r*, *b r′* represent the extreme red rays, *b v*, *b v′* the extreme violet. The aberration is greatest at the edge where the inclination of the side of the lens is greatest, and therefore where the dispersion is greatest.

By using a stop many of these extreme rays are cut off.

A lens forms an image because of the deviation; as this

deviation in a single lens is accompanied by dispersion, chromatic aberration is unavoidable. In fig. 156 the dispersion is remedied by the second prism, but the rays E are parallel to S; the emergent beam is achromatic, but there is no deviation. If the first prism be made of crown glass, its angle being 60°, a certain angle is formed between the red and violet rays. The same dispersion is produced by a flint-glass prism with an angle of 37°. Now imagine the second prism of fig. 156 to be of flint glass with an angle of 37°, then the red and violet rays on emerging will recombine. The average *deviation* caused by the first prism is 40°, the deviation caused by the second prism is $25\frac{1}{2}°$; therefore in the positions given, the general deviation will be $14\frac{1}{2}°$ $(40-25\frac{1}{2})$. Thus by two prisms we obtain deviation and avoid dispersion as far as *two* particular rays are concerned; the result is not absolutely achromatic.

Turn to lenses. Using a convex lens of crown glass (fig. 158, B), a concave lens of flint glass A is placed in contact, so that a concave surface fits closely to a convex surface. A ray meeting the convex lens would have one focus for the violet rays and one for the red rays, as in fig. 157; the effect of the flint concave glass is to correct this dispersion, as in the case of the prism. It also lessens the deviation. In practice, the dispersion for the blue and orange rays is corrected. Such a combination is called an achromatic lens; it takes the place of the single lenses in the optical instruments described.

FIG. 158.

EXAMPLES. XIII.

1. If you hold one piece of glass up to the sun it appears dark red; if you hold another up to the sun it appears dark blue. If you put the two glasses together you cannot see the sun at all through them. How is this?

2. How would you disprove, experimentally, the assertion that white light passing through a piece of coloured glass acquires colour from the glass? What is it that really happens?

3. A lamp flame, looked at through a glass prism, appears to be coloured blue on one side and red on the other. Draw a picture tracing the rays from the lamp to the eye, and showing which side of the coloured image is red, and which side is blue.

4. Given a powerful source of light, such as lime light or an electric light, explain how you could obtain a spectrum of it on a screen.

5. Explain, and illustrate by a figure, what happens to a ray of sunlight in passing through a triangular prism. Under what circumstances will the ray fail to pass through it?

6. Describe the construction of an achromatic prism, and draw a picture showing the passage of a beam of light through it.

7. Why is it that, if you look at a white sheet of paper through a slab of glass held obliquely, one edge of the paper looks blue and the other red?

8. Light enters a room through blue glass; what appearance does a red coat present in such a room?

CHAPTER VIII.

THE SPEED OF LIGHT—THE WAVE THEORY.

56. Speed of Light.

The speed at which light travels is so enormous that up to recent times philosophers believed that it moved over all space instantaneously. That light required a definite time to travel over any given space was thus discovered :—

Fig. 159.

Rœmer's Calculation.

Jupiter is a planet revolving round the sun; it has four satellites like our moon. The motion of one of these satellites had been observed, and it was found that the satellite, eclipsed at regular periods, was before its time when the earth was about T (nearest Jupiter) (fig. 159), and behind its time when the earth was at T′ (greatest distance from Jupiter); the difference was 16½ minutes. In 1675 Rœmer, a Danish astronomer, reasoned that this difference must be due to the time it takes light to travel from T to T′—that is, the diameter of the earth's orbit. This is 186,000,000 miles. 186,000,000 miles in 16½ minutes gives a speed of 188,888 miles per second.

Fizeau's Method.

Suppose we have a toothed wheel, 100 teeth and 100 spaces, and that 50 feet away from the wheel is a target. Suppose we can fire a peculiar kind of bullet in a straight line through one of the spaces, in such a way, that it is reflected back in a straight line; it will then return through the same space.

Imagine the bullet fired when the wheel is moving; then, if it travel quick enough, on returning it may just strike the first tooth; if a little later it will come through the next space.

Example.

When the wheel turns 100 times in a minute the ball is stopped by the first tooth.

The time it takes the wheel to move so that the first tooth occupies the position of the first space is $\frac{1}{2} \times \frac{1}{100} \times \frac{1}{100}$ of a minute. The ball has travelled twice 500 feet.

$\therefore$ the speed of the ball is 100 feet in $\frac{1}{20000}$ of a minute $= 2{,}000{,}000$ feet per minute.

If we double the speed of the wheel, then the bullet should get through the first space; if we treble the speed it should be stopped; with 400 turns a minute it should get through the second space. Thus the measurements could be checked. Fizeau applied this method to measure the speed of light. Light was sent through a space in a wheel with 720 teeth; it travelled to a mirror 8,663 metres away, was reflected, and after reflection passed through the space; when the wheel turned 12·6 times a second, the light was eclipsed: it was stopped by the first tooth.

$\therefore$ the time to travel (2×8663) metres was $\frac{1}{2} \times \frac{1}{720} \times \frac{1}{12{\cdot}6}$ second; that is, 17326 metres in $\frac{1}{2304}$ second;

$$\begin{aligned} \therefore \text{speed} &= 17326 \times 18144 \text{ metres per second} \\ &= \text{about } 314{,}000{,}000 \text{ metres a second.} \end{aligned}$$

The results were confirmed by doubling the speed of the wheel, when light passed through; on trebling the speed, eclipse took place.

Careful results show, that the speed is about 186,000 miles per second.

57. The Wave Theory of Light and Radiant Heat.

It is found, that the best explanation can be given of all the phenomena of light, by supposing that it travels in waves, whose particles vibrate across the line of direction as do water waves. See 'Sound,' Chap. II. § 7.

The wave lengths of violet rays are the shortest, those of the red rays the longest. These waves affecting the eye cause the sensation of violet light and red light.

When waves of all the different wave lengths strike the eye they give the sensation of white light; if any be absent colour is produced.

The particles that vibrate are not composed of air. They are supposed to pervade all space and are called ether spheres.

The number of waves in a given distance determines the colour, and the amplitude of the waves the intensity of the colour.

The fact that light is generally accompanied by heat, that when we focus light, heat is also focussed, has led to the conclusion that radiant heat is also propagated in waves, the waves being shorter than those of light; or, more correctly, light and heat are propagated by the same kind of waves. When a body is heated it causes heat waves. As the heat increases red waves (red heat) are caused, followed by white heat, in which all light waves are included. Beyond the red part of the spectrum heat can be detected, although the wave length is not sufficient to cause the sensation of light. Beyond the violet end the spectrum can affect chemical substances, and by proper arrangements can be made to emit light. These waves are known as the *Actinic waves*.

Our eyes can only be affected by light waves between certain limits; when the waves are shorter (beyond the violet) we

fail to perceive them, and when longer than the red we also fail to perceive them. There is some analogy between this and sound; when the vibrations are below 16 per second no musical note is detected, and if the vibration be beyond 30,000 per second again the note is undetected by the ear. Just as red rays and violet rays are focussed at different points when light passes through a lens, so heat rays have their own focus, which is slightly farther from the lens than the focus of the red rays

EXAMPLES. XIV.

1. Give a drawing showing clearly the 'spherical aberration' brought about by a spherical concave mirror which receives a beam of parallel rays.

2. Light (of one colour only) radiates from a point on the axis of a large convex lens, and converges on the other side of the lens. Describe and explain the effect of interposing a 'stop' (i.e. an opaque screen with circular aperture) between the source of light and the lens.

3. A beam of sunlight is brought to a focus by means of a double convex lens (not achromatised). Explain the appearance observed upon a screen placed (1) between the lens and the focus, (2) beyond the focus.

4. Explain how to obtain an achromatic image of an object by means of (*a*) prisms, (*b*) lenses.

5. Describe any way in which the velocity of light has been measured.

6. Rœmer determined the velocity of light by observations of the eclipses of one of Jupiter's moons. State clearly the nature of his observations, and the reasoning by which the velocity of light was deduced from them.

EXAMINATION QUESTIONS.

SCIENCE AND ART DEPARTMENT.

SOUND, LIGHT, AND HEAT, 1887.

First Stage, or Elementary Examination.

YOU are only permitted to *attempt eight* questions. Of these not more than *four* may be selected from the same section.

The value attached to each question is the same.

SECTION I.

1. State Boyle's law, and explain under what conditions it is true.

What will be the change in volume of a quantity of air which measures 20 cubic feet, if the pressure on it changes from 15 lbs. on the square inch to 10 lbs. on the square inch?

2. What is meant by a *wave of sound* and by the *length of a wave*? Explain how sound is transmitted through air.

3. Describe the way in which the velocity of sound in water has been determined.

4. A steel wire, one yard long and stretched by a weight of 5 lbs., vibrates 100 times per second when plucked. If I wish to make two yards of the same wire vibrate *twice* as fast, with what weight must I stretch it?

5. Describe a mouth (or flue) organ pipe. If two such pipes of the same length are sounded, one of them being open and the other closed, how do the notes differ from each other?

Section II.

6. Explain, by the aid of a sketch, how shadows are produced. Hence explain an eclipse of the sun.

7. Describe the method of using a Bunsen photometer to compare the illuminating powers of two sources of light.

8. Explain how the appearance of a stick partially immersed obliquely in water agrees with the law of refraction.

9. What do you understand by the focal length of a convex lens?

If a small object be placed so that its distance from the lens is a little greater than the focal length, where will the image be? Will it be upright or inverted, real or virtual?

10. A right-angled isosceles prism is sometimes used as a plane mirror. Explain, by the aid of a sketch, how it can be so used.

Section III.

11. How would you prove that zinc expands more than copper when rods of the two metals are heated through the same range of temperature?

12. Water is said to have its maximum density at 4° C. Explain what this means.

In what respect is the behaviour of mercury different from that of water when both are gradually warmed from 0° C.?

13. Explain, by the aid of a sketch, how a building is heated by hot water carried in pipes from a boiler in the basement of the building.

14. Define dew point. How is dew formed, and why is it more copious on some substances than on others?

15. State the effect on the volume of a given mass of air of altering its temperature without altering its pressure; also the effect on its pressure of altering its temperature without altering its volume.

Second Stage, or Advanced Examination.

Section I.

21. How would you compare the velocities of sound in different gases?

22. Describe the method of testing the state of disturbance of the air at any part of an open organ pipe, when a musical note is being produced from it.

What results will be obtained when the first harmonic is being produced from the pipe?

23. Four strings of the same material and length, but of thicknesses 1, 1·5, 2·5, and 3, are stretched on a violin and tuned so as to give successive fifths. Compare the tensions of the several strings. (The thinnest string is to give the highest note.)

24. Explain how to determine the time of vibration of a given tuning-fork, and state what apparatus you would require for the purpose.

25. Describe an experiment to prove that two sounds may produce perfect silence.

SECTION II.

26. Explain how to determine the focal length of a double convex lens without the aid of sunlight.

27. Explain how to measure the refracting angle of a prism, and the refractive index of the material of the prism.

28. Describe the method adopted by Fizeau for determining the velocity of light.

29. A brightly illuminated vertical slit in the shutter of a dark room is looked at through a prism with a vertical edge. Draw a picture showing how the image seen is formed, and explain why it is coloured.

30. A convergent pencil of light falls upon a concave lens. Trace the position of the image as the point of convergence of the pencil moves from an infinite distance up to the lens.

SECTION III.

31. Define specific heat.

A copper calorimeter having a mass of 125 grams contains 400 grams of water at 15° C.; into this are placed 556 grams of copper at a temperature of 95° C., and the final temperature is 24° C.; find the specific heat of copper.

32. What is meant by saying that the mechanical equivalent of heat is 772 foot pounds? If the standard substance were iron (whose specific heat is ·114), what would be the value of the mechanical equivalent of heat?

33. Distinguish between the apparent and the absolute expansion of mercury. Describe some method by which one *or* the other may be experimentally determined.

34. Describe the method of using a dew-point hygrometer to determine the hygrometric state of the air in a room.

35. State the laws of fusion. What is the effect of pressure in changing the temperature at which water freezes?

LONDON UNIVERSITY MATRICULATION EXAMINATION.

Selected Questions.

HEAT.

1. How is the apparent related to the absolute expansion of a liquid? A glass bottle holds 1359·6 grams of mercury at a temperature of melting ice. If the temperature be raised to that of boiling water how much mercury will be expelled from the bottle, the coefficient of expansion of mercury in the glass being ·000154?

2. State Boyle's law. If a quantity of air be saturated with aqueous vapour, will it obey Boyle's law (1) when compressed, (2) when allowed to expand; and if not, in what way will it diverge from the law?

3. Distinguish between calorimetry and thermometry.

20 grams of steam at 100° C. are condensed in a metal worm surrounded by 200 grams of water at 10° C. If the water equivalent of the worm be 10 grams, and the latent heat of steam be 536, determine the temperature to which the water is raised.

4. How would you compare the thermal conductivities of bodies whose capacities for heat per unit volume are different?

5. What is meant by a compensated pendulum? How would you construct a compensated pendulum from rods of zinc and iron, assuming that zinc expands two and a half times as much as iron under the same circumstances?

6. What is the latent heat of fusion of a substance?

A pound of ice at 0° C. is thrown into 6 pounds of water at 15° C., contained in a copper vessel weighing 3 pounds, and when the ice is melted the temperature of the water is 2° C. Find the latent heat of fusion of ice, the specific heat of copper being ·095.

7. Explain what is meant by the statement 'the coefficient of expansion of air is $\frac{1}{273}$.'

The volume of a certain quantity of air at 50° C. is 500 cubic inches. Assuming no change to take place, determine its volume at −50° C. and at 100° C. respectively.

8. Define specific heat, and describe an experiment by means of which the specific heat of oil and water may be compared.

9. B C is a zinc rod riveted at B to an iron rod B A, and at C to a second iron rod C D. Show what must be the length of the rod B C rela-

tively to the sum of the lengths A B and C D, in order that the distance of the end points A and D may not be affected by change of temperature.

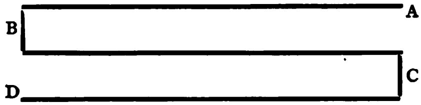


FIG. 160.

10. Explain the terms 'latent heat of water.' If the latent heat of water be represented by 80 when temperatures are measured on the Centigrade scale, what number will represent it when the temperatures are measured in the Fahrenheit scale?

11. Describe experiments to prove (1) that metals conduct heat better than wood; (2) that silver conducts better than tin; (3) that mercury conducts better than water.

12. A vessel contains air at 0° C. and at atmospheric pressure. It is heated to 100° C., and during the process one ounce of air escapes. How many ounces of air were there originally in the vessel, the expansion of the vessel itself being neglected? The coefficient of expansion of air at constant pressure is $\frac{1}{273}$.

13. If 25 grams of steam at 100° C. be passed into 300 grams of ice-cold water, what will be the temperature of the mixture, the latent heat of steam being 536?

14. Describe experiments illustrating the difference between temperature and heat.

In 100 grams of boiling water ($t = 100$) there are placed 20 grams of ice, and the temperature falls to 70° when the ice is just melted. What is the latent heat of fusion of ice, assuming no heat is lost?

15. Distinguish between saturated and unsaturated vapour.

What is meant by the statement that, when the dew point is 20° C., the maximum pressure of aqueous vapour in the air is that due to 17·4 mm. of mercury?

16. A building is heated by hot-water pipes; how does the heat get from the furnace of the boiler to a person in the building? What would be the effects on the temperature of the more distant parts of the building of coating the pipes near the boiler (*a*) with woollen felt, (*b*) with dull black lead?

LIGHT.

1. Define the centre and focal length of a lens, and show that when a real image is formed by a convex lens, the size of the image bears the same ratio to the size (linear dimensions) of the object as the distance of the image from the principal focus bears to the focal length.

2. What do you understand by an image? Draw a figure showing the way in which an image is formed by a plane reflecting surface. Will the apparent position of the image depend upon the position of the observer?

3. What laws are obeyed when a beam of light passes from one transparent medium to another? A ray of light passes from air to a certain liquid; the angle between the incident ray and the normal to a surface in air is 60°, and the angle between the reflected ray and the normal to the surface of the liquid is 45°. What is the refractive index of the liquid?

4. A bright object is placed between two plane mirrors inclined at 45°. Draw a picture showing the path of a ray of light proceeding from the object, and reaching the spectator's eye after four reflections.

5. How is the focal length of a convex lens best determined without the aid of sunlight?

An object is placed eight inches from the centre of a convex lens, and the image is found twenty-four inches from the centre on the other side of the lens. If the object were placed four inches from the centre of the lens, where would the image be?

6. State the laws of reflection of light, and draw a diagram showing under what circumstances a virtual image of an object can be formed by a concave mirror. The radius of such a mirror is six feet, and a circular disc one inch in diameter is placed on the axis of the mirror at a distance of two feet from it. Determine the size and position of the image.

7. Draw diagrams showing how a convex lens may be used either as a magnifying glass, or to form a real image of a distant object.

8. When a bright object is seen by reflection in a plate glass mirror several images are sometimes visible. Explain the formation of them. Which of them is generally brightest, and why?

9. What is meant by saying that the refractive indices of glass and water are 1·5 and 1·33 respectively? Show for which of these substances the *critical angle* or *limiting angle of refraction* is the greater.

10. An image of a candle flame, eight times as broad as the flame, is to be thrown by means of a convex lens on a wall, at a distance of twelve feet from the candle. What will be the focal length of the lens required, and where must it be placed?

11. What is meant by the refractive index of a substance, and by total internal reflection? Describe some experiment by which the phenomenon of total internal reflection may be produced and observed. State also how the minimum angle of incidence at which total internal reflection takes place may be determined.

12. Under what circumstances is total internal reflection possible? A ray of light passing through a certain medium meets the surface separating

the medium from air at an angle of 45°, and is just not reflected. What is the refractive index of the medium?

13. Two mirrors are inclined to each other at right angles. Show that three images of an object placed in the angle between the mirrors are formed, and draw the p[illegible] of rays by which the second image can be seen by an eye looking a[illegible]r.

14. What are the laws of the refraction of light? Describe some apparatus by which they can (approximately) be verified.

15. An object three inches in height is placed at a distance of six feet from a lens, and a real image is formed at a distance of three feet from the lens. The object is then placed one foot from the lens. Where, and of what height, will the image be?

CAMBRIDGE LOCAL EXAMINATIONS.

HEAT.

JUNIOR STUDENTS, 1886.

1. Explain generally the methods by which *quantity* of heat is measured. What is meant by saying that heat is a form of energy?

2. Describe an air thermometer, and point out in what respects air is advantageous as a thermometric substance. A given quantity of air at 0° C. and 760 mm. is heated in a closed vessel so that it cannot expand; its pressure is now found to be 1140 mm. Calculate the temperature to which it has been heated.

3. What is meant by the 'latent heat of fusion' of a substance? State how the fusing point of a substance is affected by pressure.

4. State the laws of conduction of heat, and mention examples of very good and very bad conductors.

5. What do you understand by the maximum pressure (or 'tension') of a vapour at a given temperature? Describe how you would show experimentally that the vapour of water exerts a pressure at ordinary temperatures.

6. Upon what conditions does the humidity, or moistness, of the air depend? What is the relative humidity of the atmosphere when the temperature is 16° C. and the dew point 9° C.?

[Maximum pressure of aqueous vapour at 9° C. = 8·5 mm.
,, ,, ,, 16° C. = 13·6 mm.]

7. Define the mechanical equivalent of heat, and describe a method of determining its value. Why should you expect that more heat would be required to raise the temperature of a given mass of gas through a certain range of temperature when its pressure remains constant, than when its volume remains constant?

Senior Students.

1. Describe any accurate method for determining the coefficient of linear expansion of a metal bar.

Show that the coefficient of cubical expansion of a solid is approximately three times the coefficient of linear expansion.

2. A quantity of air at 12° C. and 730 mm. pressure collected over water measures 250 cc. Find the volume of the dry air at 0° C. and 700 mm., explaining each step in the calculation. [Maximum pressure of aqueous vapour at 12° C. = 10·5 mm.]

3. Explain the use of the terms *saturated* and *unsaturated* vapour. Describe some experiment by which the pressure of the saturated vapour of a volatile liquid at different temperatures may be measured.

4. Define the term specific heat. A solid at a temperature of 100° C. weighing 45 grams was dropped into 120 grams of water at 15° C.; the temperature of the resulting mixture was 19°·6 C.: find the specific heat of the solid. State what further experimental data would be necessary to obtain a more accurate result.

5. A hot body is placed on a table in a room whose temperature is lower than that of the body; explain clearly how it may lose heat and how the loss may be hindered.

6. Define the term hygrometric state, and describe an experiment to determine the hygrometric state of the air.

7. Offer an explanation of the following experiment: The walls of an empty green-house are hung with black cloth; when the sun is shining the temperature of the house is found to rise rapidly; but if the black cloth is replaced by polished metal plates the house is scarcely warmed at all.

8. When the brake is applied to the wheels of a moving train it is found that the wheels become heated; account for this.

A boy can do 1200 foot pounds of work per minute; supposing that the work is applied to heating water, find how many pounds of water would be raised from 0° C. to 100° C. in half an hour, the mechanical equivalent of heat being 1390 foot pounds per centigrade unit of heat.

OXFORD LOCAL EXAMINATIONS.

HEAT.

Senior Candidates, 1886.

1. Describe the air thermometer. What are its advantages and defects as compared with the mercurial thermometer?

2. How does the pressure of a given mass of gas at constant volume vary with changes of temperature? A certain mass of gas at 15° C. is under a pressure of 743 mm. What will be the pressure if the temperature be raised to 100° C., and the volume be doubled?

3. Show how the dew point may be found by means of a condensing hygrometer.

4. Explain how it is possible to determine the height of a mountain by observations on the boiling point of water.

5. What is meant by the latent heat of fusion? How is the latent heat of water determined experimentally?

6. How may it be shown that radiant energy follows the same laws of eflection and refraction as light?

APPENDIX.

APPARATUS.

THE following is a list of the apparatus and materials needed to perform the experiments in the work. The articles in lists A, with approximate prices, are those that will probably be obtained from instrument makers. Teachers with manipulative skill and time may reduce these lists considerably. They are recommended to obtain *Outline of Experiments and Description of Apparatus and Material* prepared by the late Professor Guthrie, F.R.S., issued by the Science and Art Department. This valuable pamphlet has been frequently used in this work. Further instruction in the making of apparatus may be obtained from Weinhold's *Experimental Physics* (Longmans). The construction of the apparatus in lists B is described in the work. Details of lists C follow.

With the addition of the apparatus in italics, and omitting those with an asterisk, the lists comprise the apparatus considered by the Science and Art Department to be indispensable for the efficient teaching of the subjects.

The Department grants an aid of 50 per cent., on most of the articles mentioned, to science classes connected with it. Teachers should apply for catalogue No. 2 and forms 49 and 929.

The numbers in brackets refer to the sections.

HEAT.

A.

	s.	d.
Cryophorus	5	0
Thermometers:		
2 Centigrade, to 100° and 200°	3	9
1 Fahrenheit, to 212°	1	6
Contraction apparatus (21)	10	0
2 concave tin reflectors (71)	25	0
Set of iron balls, 4 lbs. to ½ lb., with ring handles	5	0
Stand for balls	2	6
Copper ball, 5 lbs., with ring	7	6
Set of cylinders (64). Copper, tin, lead, iron, zinc, bismuth, cork, wood	6	0
Leslie's cube (71)	2	6
1 lb. thermometer tubing	1	6
2 lbs. barometer tubing	2	6
Rods of brass, iron, etc., 18 m. (3)	0	6
Bell jar, with stopper	1	0

B.

Differential thermometer (30), unequal expansion bar (24), apparatus to show expansion of metals (3), Gravesande's ring (3).

Water hammer (1*s.* 6*d.*)

SOUND.

A.

	s.	d.
Air pump (2)	63	0
Alarum (2) (*a*)	5	0
Indiarubber tubing, 36 ft.	18	0
Fire syringe ('Heat,' § 29)	5	0
Two tuning-forks in unison	8	0
One tuning-fork octave higher	4	0
Iron table vice, with cork-lined clamp	7	6
Violin bow (1)	4	0
*Organ pipe to show nodes	40	0
2 tin tubes, each 3 ft. × 4 ins.	6	0
Toy balloon		
Gas cylinder, 12 ins. (35)	1	3
Strong globular flask (2)	1	6
Child's whistle (40)		
Deal rod, 12 ft. by 1 in. by ½ in. (*b*)		
Thin deal board, 24 ins. sq. (*c*)		
2 round deal rods, 6 ft. × ½ in.		
2 round oak rods, 6 ft. × ½ in.		
Hand bell (*d*)		

(*a*) Use common alarum clock.
(*b*) Cover with list, suspend by threads, and use for sounding board.
(*c*) Use for sounding board.
(*d*) Use stoppered bell jar ('Heat').

B.

Boyle's tube on board with scale ('Heat,' § 25).

C.

(*a*) Savart s toothed wheel; (*b*) siren; (*c*) humming-top fitted with Savart's wheel; (*d*) monochord); (*e*) square of glass (1); (*f*) set of weights, 3 of 10 lbs., 1 of 20 lbs.; (*g*) long trough (6), 4 ft. by 6 ins. by 6 ins., with glass front.

Round trough to show wave motion.

Box for showing vortex rings.

(*a*) *Savart's Wheel.*—A thin sheet-iron wheel of 24 centimetres diameter; divide the circumference into 24 parts; notch in each part six teeth.

(*b*) *Siren.*—A thin sheet of good, smooth, stiff card board. From the centre *c* draw circles having the following radii: 8·5, 9·5, 10·5, 11·5, and

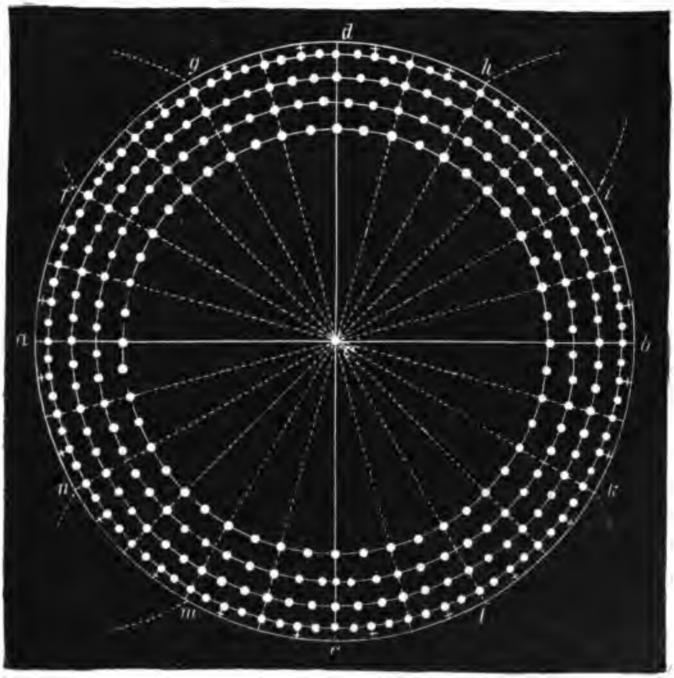


FIG. 161.

12 centimetres. By geometrical means draw diameters *ab*, *cd*; then obtain the points *f*, *g*, *h*, *i*; join the opposite points; the circle is now divided into

twelve parts; divide each part of the circle having the radius 9·5 centimetres into five parts. Bisect each twelfth part, and draw the radii; now bisect each part of inner circle, trisect the parts of the third circle, and divide the parts of the outer circle into four parts. Indicate the points carefully, and have the holes punched by a saddler. The first three circles of holes will be sufficient for ordinary experiments. These sizes are for use with the whirling table, one half size for top.

(*c*) Fill a large humming-top with sand, seal the hole, then drive a small smooth-headed nail into the peg. Cut the upper stem so that the section is that of an equilateral triangle. Now puncture holes corresponding with this section in the centre of the wheels. Fasten the wheels to the top by means of washers with triangular apertures. Spin on the bottom of a tumbler.

If possible obtain a whirling table (fig. 162); the action is more under control (cost 1*l.* 13*s.*) An old foot or hand sewing-machine, with the body removed, when adapted to receive the wheels, would suit admirably.

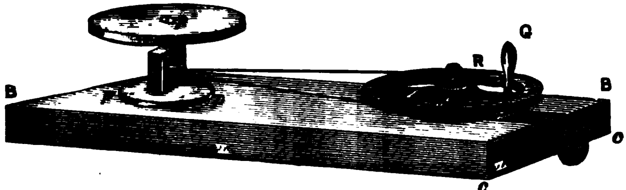


FIG. 162.

(*d*) *Monochord.*—An inch deal board, 3 feet long, 9 inches wide; two pieces of wood 6 inches × 1 inch × 1 inch, screwed on across ends of board, to form supports. Three long wooden screws driven in obliquely (slanting outwards) at one end at equal distances. At the other end opposite one screw is a pianoforte peg at an angle of 45°. Opposite the other two screws are two brass pulleys (window blind pulleys) on stems which are driven in at an angle of 45°. A bridge—that is, a triangular wedge of hard wood—9 inches long, ½ inch wide at base, and as high as the pulleys. This is screwed from below across the board, about 3 inches from the wooden screws. Three other little movable bridges about 1 inch long, as high as the pulleys, are provided. A variety of weights and hooks; a pair of pliers; several yards of iron wire (pianoforte wires) of different thicknesses; brass wire, some of which has the same thickness as some of the iron wire. The ends of three pieces of wire are twisted into loops and passed over the screw-heads. One of the other ends is passed through the pianoforte peg, which is then twisted round by the pliers. The other two have loops twisted in them, and, passing over the pulleys, carry weights.

A sheet of paper is gummed to the board, having lines at every inch

and thinner ones at every $\frac{1}{10}$ inch. Mark with 0 the line beneath the pulleys and at the pianoforte peg.—*Molecular Physics*, F. Guthrie.

(*e*) A square of strong window glass, 9 ins. side; file the edges and smooth on a stone.

(*f*) Buy $\frac{1}{2}$ cwt. of scrap-lead. Melt a little over 10 lbs. in a ladle; remove the scum; make a cylindrical hole 4 inches diameter, in moist clay, with a wooden cylinder. Into the middle of the base insert a stout iron wire so that 2 inches are in the clay. Pour in the lead. When cold bend the wire to form a hook at each end. Correct the weight with standard weights, file off the necessary amounts. Similarly make the others. Use with these the 4-lb. to $\frac{1}{4}$-lb. iron weights.

(*g*) The wood should be $\frac{1}{2}$-inch deal. Make watertight with marine glue; paint the inside white.

LIGHT.

A.

	s.	*d.*		*s.*	*d.*
*Lantern	90	0	Glass trough with 5 divisions (38)	6	0
Set of lenses	20	0	Carbon disulphide prism	10	0
Frame for lenses	5	0	Prisms, 2 equilateral (51)	6	0
2 concave mirrors	20	0	Prisms, 1 rectangular (39)	4	0
1 convex mirror	16	0	Square of roughened glass		
2 wedge-shaped cells	9	0	Strips of coloured glass	5	0
2 flat glass cells	5	0	2 ground-glass globes (3)		
Strips of plate glass					
Strips of crown glass					

* A lantern at this price will answer also for advanced optical work. As far as the spectrum experiments in the work are concerned, a cheaper form will suffice. If the classes be held during the day, sunlight may be used.

B.

	s.	*d.*		*s.*	*d.*
Newton's colour disc (51)			Refraction apparatus (31)	5	0

C.

(*a*) Blackened glass. (*b*) Blackened paper.

(*a*) Warm the glass, rub with solid paraffin, remelt and drain off as much as possible; light a piece of camphor, hold paraffined side in the smoke. Remove black with a needle.

(*b*) Dissolve as much shellac as possible in methylated alcohol; allow the mixture to stand for 24 hours; pour off; add to solution as much again of alcohol; add lampblack. Paint cardboard with this.

Phosphorescence tube.

Model of eye on foot.

GENERAL APPARATUS.

	s.	d.
Balance, to carry 1 kilo.	30	0
Weights, 1 kilo. to 1 decigram	12	6
Two retort stands with clamps	10	0
Iron tripod	1	3
2 Bunsen burners	5	0
Spirit lamp	2	0
3 dozen assorted test tubes	2	6
Set of 6 beakers	3	6
1 dozen assorted flasks: 4 of 2 oz., 2 of 4 oz., 2 of 6 oz., 2 of 8 oz., 1 of 12 oz., 1 of 16 oz.	6	0
$\frac{1}{2}$ dozen indiarubber corks	1	3

	s.	d.
3 dozen ordinary corks	1	0
Cork borers, small set	2	0
3 lbs. glass tubing	3	0
$\frac{1}{2}$ lb. glass rod	0	6
Platinum wire	0	6
2 ft. indiarubber tubing ($\frac{3}{8}$ in.)	1	0
Tinfoil	0	6
1 sq. ft. iron gauze, coarse	0	10
,, fine	0	10
Iron and copper wire	1	0
1 sq. ft. iron plate	0	6
2 sq. ft. tin plate	0	6
Metre scale	1	6
Retort stoppered	0	9

CHEMICALS.

	s.	d.
Ether meth., 2 oz.	0	7
Turpentine, 2 oz.	0	2
Alcohol, 2 oz. pure	0	9
Alcohol, meth., 1 pint	0	6
Carbon disulphide, pure, 4 oz.	1	6
Sulphuric acid, 1 pint	1	0

	s.	d.
Hydrochloric acid, 1 pint	1	0
Sodium sulphate, 1 lb.	0	4
Tincture of iodine, 1 oz.	0	2
Sulphur, 1 lb.	0	3
Resin	0	3
Calcium chloride, $\frac{1}{2}$ lb.	0	6
Mercury, 5 lbs.	price varies	

ANSWERS.

HEAT.

II. (1) 30. (2) ·5 in.

III. (4) 81·7° F. (5) F°. 122, 50, 19·4, 356, 90·5. (6) C°. 32·2, −1·1, −9·4, 0, 82·2.

IV. (6) (*a*) F°. 59, 86, 63·5, 32, 212, −22, 14; R°. 12, 24, 14, 0, 80, −24, −8. (*b*) C°. 82·2, 100, 21·1, 15·5, −24·4; R°. 65·8, 80, 16·9, 12·4, −19·5.

VI. (1) ·00001875. (2) ·000008.

VII. (1) ·0432 in. too long. (2) 352 yds. (rails of cast iron). (4) 1 ft. 3·0027 ins. (5) ·08512 in. (6) ·9792 in.

VIII. (2) 4·00228 (coeff. of lin. exp. = ·000019).

IX. (2) ·000000000867004913 cub. ft. (4) 120·306 cub. ins. (5) 1·008415 cub. ft. (8) 20·054 cub. ins.

X. (1) ·000026. (2) ·000461.

XII. (8) No change. (10) Zinc : iron :: 12 : 30.

XIII. (2) 10 cub. ft. (3) 106·6̇ cub. cm.

XIV. (1) 189·89 cub. ins. (2) 254·3 cub. ft. (3) 763·9 cub. ins.

XV. (1) 12·37 grains. (2) 13·59 grams.

XVI. (1) 719 grams. (2) 81·2 cub. ft. (3) 1·46 cub. ft.

XVII. (3) ·095, 4·75. (5) 60, 5.

XVIII. (1) ·0974. (2) 44·8°. (3) 96·8°. (4) 755·8° C. (5) 55·5̇.

XIX. (1) 551·3° C. (2) 1·72 lb. (3) ·444.

XX. (3) ·092. (4) 5·66 lbs.

XXI. (1) 11,000,000.

XXIII. (4) 536·6̇.

XXIV. (9) ·55. (10) 1109·5 grams.

XXV. (7) 16848 *c.g.s.* (8) 30·1.

XXVIII. (1) 3·1 ft. (2) 292·7 units. lb. F. (3) 4·32° F. (4) ·24° C. (5) ·375 lb. (6) 6·3 lbs. (7) 7180.

SOUND.

I. (6) 2240 yds.

II. (6) 20 ft.

III. (7) Elasticity is equal to a pressure of 31 cubic ins. of mercury per sq. in. (8) (*a*) 4 ft.; (*b*) $2\frac{6}{11}$ ft. (9) 1200 ft. per sec.

IV. (4) $\frac{20}{21}$ sec. (7) 3711·885 metres per sec.

V. (1) 40. (4) 16800 ft. per sec. at 15° C. (6) Intens. at 1100 : intens. at 1800 :: 324 : 121.

VII. (2) 120, 144, 192. (4) 264, 297, 330, 352, 396, 440, 495, 528. (5) 120.

VIII. (3) 36·3. (7) 120.

IX. (2) 426·6. (4) 4 lbs. (6) Vib. nos. are as $1 : \frac{2}{3} : \frac{4}{9} : \frac{8}{27}$; the diameters are as $1 : \frac{3}{2} : \frac{9}{4} : \frac{27}{8}$. (7) $1 : \frac{9}{4} : \frac{81}{16} : \frac{629}{64}$.

XI. (1) 120. (2) Vib. no. of fund. : overtone :: $2^2 : 5^2$; if vib. no. of C be 4, then vib. no. of C″ is 16, and of G″ 24. The overtone is above G″.

XII. (2) $13\frac{1}{8}$ ins., $52\frac{1}{2}$ ins. at 15° C. (5) 8·59 ins., 34·4 ins.

XIII. (4) Vib. no. of stopped : vib. no. of open :: 3 : 2. (5) 35 ins., $17\frac{1}{2}$ ins.

XIV. (5) Vib. nos. become 1200, 100, 800, and $133\frac{1}{3}$. (6) $28\frac{2}{7}$ sec. Temp. omitted. (11) Length of silver : length of iron :: 1 : ·287. (12) 4 ft., vib. no. $271\frac{1}{4}$.

LIGHT.

I. (5) 144 sq. ins.

II. (3) 10 ft. (6) $4\frac{2}{3}$ ins. diam.

V. (6) 60°.

VI. (1) $f = 10$. (2) $f = 20·9$ ins., $r = 41·8$ ins. (3) $f = 18\frac{3}{4}$, $u = 12·5$, $v = 25$, $f = 10$. (4) (*a*) 9 ins. from the mirror; (*b*) virtual, 30 ins. behind.

VII. (1) 10, 24, 1·5, and 6 ins. (4) 13·5 ins.

VIII. (3) $48\frac{1}{2}$, 42, 37, $23\frac{1}{3}$ (approximate).

X. (4) Two.

XI. (1) 3 ins. (2) Virtual, 9 ins. in front of lens; $1\frac{1}{4}$ in. in diam. (4) Smaller, real, 9 ins. from eye. (6) 4 ins.

EXAMINATION QUESTIONS.

SCIENCE AND ART DEPARTMENT.

(1) 30 cubic ft. (4) 80 lbs.
(23) 81 : 81 : 100 : 64. (31) ·094 nearly. (32) 88 nearly.

LONDON UNIVERSITY.

HEAT.

(1) 20·6 grams. (3) 64·4° C. (5) $\frac{\text{Zinc}}{\text{Iron}}=\frac{2}{5}$. (6) 79·705. (7) 345·2, 577·4. (9) $\frac{BC}{AB+CD}=\frac{2}{5}$ (roughly). (12) 3·73 oz. (13) 48·8° C. (14) 80.

LIGHT.

(3) 1·22. (5) Virtual, on same side as object, 12 ins. from the mirror. (6) Virtual, 6 ins. from the mirror, 3 ins. diameter. (9) Water. (10) $\frac{4}{3}$ ft. from the candle. $f=\frac{32}{27}$. (12) $\sqrt{2}$. (15) 2 ft. from the lens, virtual; 6 ins. high.

CAMBRIDGE LOCALS.

HEAT.

JUNIOR STUDENTS.

(2) 136·5° C. (6) ·64.

SENIOR STUDENTS.

(2) 246 c.cms. (4) ·15. (8) $\frac{36}{139}$ lb.

OXFORD LOCALS.

(2) 481.

INDEX.

PRINTED BY
SPOTTISWOODE AND CO., NEW-STREET SQUARE
LONDON

3

1 : 3 1

3 2 1 2

1

$\frac{3}{2}$

6

AUGUST 1887.

GENERAL LISTS OF WORKS

PUBLISHED BY

MESSRS. LONGMANS, GREEN, & CO.

39 PATERNOSTER ROW, LONDON, E.C.; AND
15 EAST 16th STREET, NEW YORK.

HISTORY, POLITICS, HISTORICAL MEMOIRS, &c.

Abbey's The English Church and its Bishops, 1700–1800. 2 vols. 8vo. 24*s.*

Abbey and Overton's English Church in the Eighteenth Century. Cr. 8vo. 7*s.* 6*d.*

Arnold's Lectures on Modern History. 8vo. 7*s.* 6*d.*

Bagwell's Ireland under the Tudors. Vols. 1 and 2. 2 vols. 8vo. 32*s.*

Ball's The Reformed Church of Ireland, 1537–1886. 8vo. 7*s.* 6*d.*

Boultbee's History of the Church of England, Pre-Reformation Period. 8vo. 15*s.*

Buckle's History of Civilisation. 3 vols. crown 8vo. 24*s.*

Cox's (Sir G. W.) General History of Greece. Crown 8vo. Maps, 7*s.* 6*d.*

Creighton's History of the Papacy during the Reformation. 8vo. Vols. 1 and 2, 32*s.* Vols. 3 and 4, 24*s.*

De Tocqueville's Democracy in America. 2 vols. crown 8vo. 16*s.*

D'Herisson's The Black Cabinet. Crown 8vo. 7*s.* 6*d.*

Doyle's English in America: Virginia, Maryland, and the Carolinas, 8vo. 18*s.*

— — — The Puritan Colonies, 2 vols. 8vo. 36*s.*

Epochs of Ancient History. Edited by the Rev. Sir G. W. Cox, Bart. and C. Sankey, M.A. With Maps. Fcp. 8vo. price 2*s.* 6*d.* each.

- Beesly's Gracchi, Marius, and Sulla.
- Capes's Age of the Antonines.
- — Early Roman Empire.
- Cox's Athenian Empire.
- — Greeks and Persians.
- Curteis's Rise of the Macedonian Empire.
- Ihne's Rome to its Capture by the Gauls.
- Merivale's Roman Triumvirates.
- Sankey's Spartan and Theban Supremacies.
- Smith's Rome and Carthage, the Punic Wars.

Epochs of Modern History. Edited by C. Colbeck, M.A. With Maps. Fcp. 8vo. price 2*s.* 6*d.* each.

- Church's Beginning of the Middle Ages.
- Cox's Crusades.
- Creighton's Age of Elizabeth.
- Gairdner's Houses of Lancaster and York.
- Gardiner's Puritan Revolution.
- — Thirty Years' War.
- — (Mrs.) French Revolution, 1789–1795.
- Hale's Fall of the Stuarts.
- Johnson's Normans in Europe.
- Longman's Frederick the Great and the Seven Years' War.
- Ludlow's War of American Independence.
- M'Carthy's Epoch of Reform, 1830–1850.
- Moberly's The Early Tudors.
- Morris's Age of Queen Anne.
- — The Early Hanoverians.
- Seebohm's Protestant Revolution.
- Stubbs's The Early Plantagenets.
- Warburton's Edward III.

Epochs of Church History. Edited by the Rev. Mandell Creighton, M.A. Fcp. 8vo. price 2*s.* 6*d.* each.

- Brodrick's A History of the University of Oxford.
- Carr's The Church and the Roman Empire.
- Overton's The Evangelical Revival in the Eighteenth Century.
- Perry's The Reformation in England.
- Plummer's The Church of the Early Fathers.
- Tucker's The English Church in other Lands.

*** *Other Volumes in preparation.*

LONGMANS, GREEN, & CO. London and New York.

BIOGRAPHICAL WORKS

Armstrong's (E. J.) Life and Letters. Edited by G. F. Armstrong. Fcp. 8vo. 7*s*. 6*d*.
Bacon's Life and Letters, by Spedding. 7 vols. 8vo. £4. 4*s*.
Bagehot's Biographical Studies. 1 vol. 8vo. 12*s*.
Carlyle's Life, by J. A. Froude. Vols. 1 & 2, 1795–1835, 8vo. 32*s*. Vols. 3 & 4, 1834–1881, 8vo. 32*s*.
— (Mrs.) Letters and Memorials. 3 vols. 8vo. 36*s*.
Doyle (Sir F. H.) Reminiscences and Opinions. 8vo. 16*s*.
English Worthies. Edited by Andrew Lang. Crown 8vo. 2*s*. 6*d*. each.
Charles Darwin. By Grant Allen.
Shaftesbury (The First Earl). By H. D. Traill.
Admiral Blake. By David Hannay.
Marlborough. By Geo. Saintsbury.
Steele. By Austin Dobson.
Ben Jonson. By J. A. Symonds.
George Canning. By Frank H. Hill.
Claverhouse. By Mowbray Morris.
*** *Other Volumes in preparation.*
Fox (Charles James) The Early History of. By Sir G. O. Trevelyan, Bart. Crown 8vo. 6*s*.
Froude's Cæsar: a Sketch. Crown 8vo. 6*s*.
Hamilton's (Sir W. R.) Life, by Graves. Vols. 1 and 2, 8vo. 15*s*. each.
Havelock's Life, by Marshman. Crown 8vo. 3*s*. 6*d*.
Hobart Pacha's Sketches from my Life. Crown 8vo. 7*s*. 6*d*.
Macaulay's (Lord) Life and Letters. By his Nephew, Sir G. O. Trevelyan, Bart. Popular Edition, 1 vol. crown 8vo. 6*s*. Cabinet Edition, 2 vols. post 8vo. 12*s*. Library Edition, 2 vols. 8vo. 36*s*.
Mendelssohn's Letters. Translated by Lady Wallace. 2 vols. cr. 8vo. 5*s*. each.
Mill (James) Biography of, by Prof. Bain. Crown 8vo. 5*s*.
— (John Stuart) Recollections of, by Prof. Bain. Crown 8vo. 2*s*. 6*d*.
— — Autobiography. 8vo. 7*s*. 6*d*.
Müller's (Max) Biographical Essays. Crown 8vo. 7*s*. 6*d*.
Newman's Apologia pro Vitâ Suâ. Crown 8vo. 6*s*.
Pasteur (Louis) His Life and Labours. Crown 8vo. 7*s*. 6*d*.
Shakespeare's Life (Outlines of), by Halliwell-Phillipps. 2 vols. royal 8vo. 10*s*. 6*d*.
Southey's Correspondence with Caroline Bowles. 8vo. 14*s*.
Stephen's Essays in Ecclesiastical Biography. Crown 8vo. 7*s*. 6*d*.
Wellington's Life, by Gleig. Crown 8vo. 6*s*.

MENTAL AND POLITICAL PHILOSOPHY, FINANCE, &c.

Amos's View of the Science of Jurisprudence. 8vo. 18*s*.
— Primer of the English Constitution. Crown 8vo. 6*s*.
Bacon's Essays, with Annotations by Whately. 8vo. 10*s*. 6*d*.
— Works, edited by Spedding. 7 vols. 8vo. 73*s*. 6*d*.
Bagehot's Economic Studies, edited by Hutton. 8vo. 10*s*. 6*d*.
— The Postulates of English Political Economy. Crown 8vo. 2*s*. 6*d*.
Bain's Logic, Deductive and Inductive. Crown 8vo. 10*s*. 6*d*.
Part I. Deduction, 4*s*. | Part II. Induction, 6*s*. 6*d*.
— Mental and Moral Science. Crown 8vo. 10*s*. 6*d*.
— The Senses and the Intellect. 8vo. 15*s*.
— The Emotions and the Will. 8vo. 15*s*.
— Practical Essays. Crown 8vo. 4*s*. 6*d*.

Buckle's (H. T.) Miscellaneous and Posthumous Works. 2 vols. crown 8vo. 21*s.*
Crump's A Short Enquiry into the Formation of English Political Opinion. 8vo. 7*s.* 6*d.*
Dowell's A History of Taxation and Taxes in England. 4 vols. 8vo. 48*s.*
Green's (Thomas Hill) Works. (3 vols.) Vols. 1 & 2, Philosophical Works. 8vo. 16*s.* each.
Hume's Essays, edited by Green & Grose. 2 vols. 8vo. 28*s.*
— Treatise of Human Nature, edited by Green & Grose. 2 vols. 8vo. 28*s.*
Ladd's Elements of Physiological Psychology. 8vo. 21*s.*
Lang's Custom and Myth: Studies of Early Usage and Belief. Crown 8vo. 7*s.* 6*d.*
Leslie's Essays in Political and Moral Philosophy. 8vo. 10*s.* 6*d.*
Lewes's History of Philosophy. 2 vols. 8vo. 32*s.*
Lubbock's Origin of Civilisation. 8vo. 18*s.*
Macleod's Principles of Economical Philosophy. In 2 vols. Vol. 1, 8vo. 15*s.* Vol. 2, Part I. 12*s.*
— The Elements of Economics. (2 vols.) Vol. 1, cr. 8vo. 7*s.* 6*d.* Vol. 2, Part I. cr. 8vo. 7*s.* 6*d.*
— The Elements of Banking. Crown 8vo. 5*s.*
— The Theory and Practice of Banking. Vol. 1, 8vo. 12*s.* Vol. 2, 14*s.*
— Economics for Beginners. 8vo. 2*s.* 6*d.*
— Lectures on Credit and Banking. 8vo. 5*s.*
Mill's (James) Analysis of the Phenomena of the Human Mind. 2 vols. 8vo. 28*s.*
Mill (John Stuart) on Representative Government. Crown 8vo. 2*s.*
— — on Liberty. Crown 8vo. 1*s.* 4*d.*
— — Examination of Hamilton's Philosophy. 8vo. 16*s.*
— — Logic. Crown 8vo. 5*s.*
— — Principles of Political Economy. 2 vols. 8vo. 30*s.* People's Edition, 1 vol. crown 8vo. 5*s.*
— — Subjection of Women. Crown 8vo. 6*s.*
— — Utilitarianism. 8vo. 5*s.*
— — Three Essays on Religion, &c. 8vo. 5*s.*
Mulhall's History of Prices since 1850. Crown 8vo. 6*s.*
Müller's The Science of Thought. 8vo. 21*s.*
Sandars's Institutes of Justinian, with English Notes. 8vo. 18*s.*
Seebohm's English Village Community. 8vo. 16*s.*
Sully's Outlines of Psychology. 8vo. 12*s.* 6*d.*
— Teacher's Handbook of Psychology. Crown 8vo. 6*s.* 6*d.*
Swinburne's Picture Logic. Post 8vo. 5*s.*
Thompson's A System of Psychology. 2 vols. 8vo. 36*s.*
— The Problem of Evil. 8vo. 10*s.* 6*d.*
Thomson's Outline of Necessary Laws of Thought. Crown 8vo. 6*s.*
Twiss's Law of Nations in Time of War. 8vo. 21*s.*
— — in Time of Peace. 8vo. 15*s.*
Webb's The Veil of Isis. 8vo. 10*s.* 6*d.*
Whately's Elements of Logic. Crown 8vo. 4*s.* 6*d.*
— — — Rhetoric. Crown 8vo. 4*s.* 6*d.*
Wylie's Labour, Leisure, and Luxury. Crown 8vo. 6*s.*
Zeller's History of Eclecticism in Greek Philosophy. Crown 8vo. 10*s.* 6*d.*
— Plato and the Older Academy. Crown 8vo. 18*s.*
— Pre-Socratic Schools. 2 vols. crown 8vo. 30*s.*
— Socrates and the Socratic Schools. Crown 8vo. 10*s.* 6*d.*
— Stoics, Epicureans, and Sceptics. Crown 8vo. 15*s.*
— Outlines of the History of Greek Philosophy. Crown 8vo. 10*s.* 6*d.*

MISCELLANEOUS WORKS.

A. K. H. B., The Essays and Contributions of. Crown 8vo.
- Autumn Holidays of a Country Parson. 3*s.* 6*d.*
- Changed Aspects of Unchanged Truths. 3*s.* 6*d.*
- Common-Place Philosopher in Town and Country. 3*s.* 6*d.*
- Critical Essays of a Country Parson. 3*s.* 6*d.*
- Counsel and Comfort spoken from a City Pulpit. 3*s.* 6*d.*
- Graver Thoughts of a Country Parson. Three Series. 3*s.* 6*d.* each.
- Landscapes, Churches, and Moralities. 3*s.* 6*d.*
- Leisure Hours in Town. 3*s.* 6*d.* Lessons of Middle Age. 3*s.* 6*d.*
- Our Homely Comedy; and Tragedy. 3*s.* 6*d.*
- Our Little Life. Essays Consolatory and Domestic. Two Series. 3*s.* 6*d.* [each.
- Present-day Thoughts. 3*s.* 6*d.*
- Recreations of a Country Parson. Three Series. 3*s.* 6*d.* each.
- Seaside Musings on Sundays and Week-Days. 3*s.* 6*d.*
- Sunday Afternoons in the Parish Church of a University City. 3*s.* 6*d.*

Armstrong's (Ed. J.) Essays and Sketches. Fcp. 8vo. 5*s.*
Arnold's (Dr. Thomas) Miscellaneous Works. 8vo. 7*s.* 6*d.*
Bagehot's Literary Studies, edited by Hutton. 2 vols. 8vo. 28*s.*
Beaconsfield (Lord), The Wit and Wisdom of. Crown 8vo. 1*s.* boards; 1*s.* 6*d.* cl.
Evans's Bronze Implements of Great Britain. 8vo. 25*s.*
Farrar's Language and Languages. Crown 8vo. 6*s.*
Froude's Short Studies on Great Subjects. 4 vols. crown 8vo. 24*s.*
Lang's Letters to Dead Authors. Fcp. 8vo. 6*s.* 6*d.*
— Books and Bookmen. Crown 8vo. 6*s.* 6*d.*
Macaulay's Miscellaneous Writings. 2 vols. 8vo. 21*s.* 1 vol. crown 8vo. 4*s.* 6*d.*
— Miscellaneous Writings and Speeches. Crown 8vo. 6*s.*
— Miscellaneous Writings, Speeches, Lays of Ancient Rome, &c. Cabinet Edition. 4 vols. crown 8vo. 24*s.*
— Writings, Selections from. Crown 8vo. 6*s.*
Müller's (Max) Lectures on the Science of Language. 2 vols. crown 8vo. 16*s.*
— — Lectures on India. 8vo. 12*s.* 6*d.*
Proctor's Chance and Luck. Crown 8vo. 5*s.*
Smith (Sydney) The Wit and Wisdom of. Crown 8vo. 1*s.* boards; 1*s.* 6*d.* cloth.

ASTRONOMY.

Herschel's Outlines of Astronomy. Square crown 8vo. 12*s.*
Proctor's Larger Star Atlas. Folio, 15*s.* or Maps only, 12*s.* 6*d.*
— New Star Atlas. Crown 8vo. 5*s.*
— Light Science for Leisure Hours. 3 Series. Crown 8vo. 5*s.* each.
— The Moon. Crown 8vo. 6*s.*
— Other Worlds than Ours. Crown 8vo. 5*s.*
— The Sun. Crown 8vo. 14*s.*
— Studies of Venus-Transits. 8vo. 5*s.*
— Orbs Around Us. Crown 8vo. 5*s.*
— Universe of Stars. 8vo. 10*s.* 6*d.*
Webb's Celestial Objects for Common Telescopes. Crown 8vo. 9*s.*

THE 'KNOWLEDGE' LIBRARY.

Edited by Richard A. Proctor.

How to Play Whist. Crown 8vo. 5*s.*
Home Whist. 16mo. 1*s.*
The Borderland of Science. Cr. 8vo. 6*s.*
Nature Studies. Crown 8vo. 6*s.*
Leisure Readings. Crown 8vo. 6*s.*
The Stars in their Seasons. Imp. 8vo. 5*s.*
Myths and Marvels of Astronomy. Crown 8vo. 6*s.*
Pleasant Ways in Science. Cr. 8vo. 6*s.*
Star Primer. Crown 4to. 2*s.* 6*d.*
The Seasons Pictured. Demy 4to. 5*s.*
Strength and Happiness. Cr. 8vo. 5*s.*
Rough Ways made Smooth. Cr. 8vo. 6*s.*
The Expanse of Heaven. Cr. 8vo. 5*s.*
Our Place among Infinities. Cr. 8vo. 5*s.*

CLASSICAL LANGUAGES AND LITERATURE.

Æschylus, The Eumenides of. Text, with Metrical English Translation, by J. F. Davies. 8vo. 7s.

Aristophanes' The Acharnians, translated by R. Y. Tyrrell. Crown 8vo. 2s. 6d.

Aristotle's The Ethics, Text and Notes, by Sir Alex. Grant, Bart. 2 vols. 8vo. 32s.

— The Nicomachean Ethics, translated by Williams, crown 8vo. 7s. 6d.

— The Politics, Books I. III. IV. (VII.) with Translation, &c. by Bolland and Lang. Crown 8vo. 7s. 6d.

Becker's *Charicles* and *Gallus*, by Metcalfe. Post 8vo. 7s. 6d. each.

Cicero's Correspondence, Text and Notes, by R. Y. Tyrrell. Vols. 1 & 2, 8vo. 12s. each.

Homer's Iliad, Homometrically translated by Cayley. 8vo. 12s. 6d.

— — Greek Text, with Verse Translation, by W. C. Green. Vol. 1, Books I.–XII. Crown 8vo. 6s.

Mahaffy's Classical Greek Literature. Crown 8vo. Vol. 1, The Poets, 7s. 6d. Vol. 2, The Prose Writers, 7s. 6d.

Plato's Parmenides, with Notes, &c. by J. Maguire. 8vo. 7s. 6d.

Virgil's Works, Latin Text, with Commentary, by Kennedy. Crown 8vo. 10s. 6d.

— Æneid, translated into English Verse, by Conington. Crown 8vo. 9s.

— — — — — — by W. J. Thornhill. Cr. 8vo. 7s. 6d.

— Poems, — — — Prose, by Conington. Crown 8vo. 9s.

Witt's Myths of Hellas, translated by F. M. Younghusband. Crown 8vo. 3s. 6d.

— The Trojan War, — — Fcp. 8vo. 2s.

— The Wanderings of Ulysses, — Crown 8vo. 3s. 6d.

NATURAL HISTORY, BOTANY, & GARDENING.

Allen's Flowers and their Pedigrees. Crown 8vo. Woodcuts, 5s.

Decaisne and Le Maout's General System of Botany. Imperial 8vo. 31s. 6d.

Dixon's Rural Bird Life. Crown 8vo. Illustrations, 5s.

Hartwig's Aerial World, 8vo. 10s. 6d.

— Polar World, 8vo. 10s. 6d.

— Sea and its Living Wonders. 8vo. 10s. 6d.

— Subterranean World, 8vo. 10s. 6d.

— Tropical World, 8vo. 10s. 6d.

Lindley's Treasury of Botany. 2 vols. fcp. 8vo. 12s.

Loudon's Encyclopædia of Gardening. 8vo. 21s.

— — Plants. 8vo. 42s.

Rivers's Orchard House. Crown 8vo. 5s.

— Miniature Fruit Garden. Fcp. 8vo. 4s.

Stanley's Familiar History of British Birds. Crown 8vo. 6s.

Wood's Bible Animals. With 112 Vignettes. 8vo. 10s. 6d.

— Common British Insects. Crown 8vo. 3s. 6d.

— Homes Without Hands, 8vo. 10s. 6d.

— Insects Abroad, 8vo. 10s. 6d.

— Horse and Man. 8vo. 14s.

— Insects at Home. With 700 Illustrations. 8vo. 10s. 6d.

— Out of Doors. Crown 8vo. 5s.

— Petland Revisited. Crown 8vo. 7s. 6d.

— Strange Dwellings. Crown 8vo. 5s. Popular Edition, 4to. 6d.

PRIZE AND PRESENTATION BOOKS.

Jameson's Sacred and Legendary Art. 6 vols. square 8vo.
Legends of the Madonna. 1 vol. 21*s*.
— — — Monastic Orders 1 vol. 21*s*.
— — — Saints and Martyrs. 2 vols. 31*s*. 6*d*.
— — — Saviour. Completed by Lady Eastlake. 2 vols. 42*s*.

Macaulay's Lays of Ancient Rome, illustrated by Scharf. Fcp. 4to. 10*s*. 6*d*.

The same, with *Ivry* and the *Armada*, illustrated by Weguelin. Crown 8vo. 3*s*. 6*d*.

New Testament (The) illustrated with Woodcuts after Paintings by the Early Masters. 4to. 21*s*.

By Dr. G. Hartwig.

Sea Monsters and Sea Birds (from 'The Sea and its Living Wonders'). With 75 Illustrations. Crown 8vo. 2*s*. 6*d*. cloth extra, gilt edges.

Denizens of the Deep (from 'The Sea and its Living Wonders'). With 117 Illustrations. Crown 8vo. 2*s*. 6*d*. cloth extra, gilt edges.

Dwellers in the Arctic Regions (from 'The Sea and its Living Wonders'). With 29 Illustrations. Crown 8vo. 2*s*. 6*d*. cloth extra, gilt edges.

Winged Life in the Tropics (from 'The Tropical World'). With 55 Illustrations. Crown 8vo. 2*s*. 6*d*. cloth extra, gilt edges.

Volcanoes and Earthquakes (from 'The Subterranean World'). With 30 Illustrations. Crown 8vo. 2*s*. 6*d*. cloth extra, gilt edges.

Wild Animals of the Tropics (from 'The Tropical World'). With 66 Illustrations. Crown 8vo. 3*s*. 6*d*. cloth extra, gilt edges.

By the Rev. J. G. Wood.

The Branch Builders (from 'Homes without Hands'). With 28 Illustrations. Crown 8vo. 2*s*. 6*d*. cloth extra, gilt edges.

Wild Animals of the Bible (from 'Bible Animals'). With 29 Illustrations. Crown 8vo. 3*s*. 6*d*. cloth extra, gilt edges.

Domestic Animals of the Bible (from 'Bible Animals'). With 23 Illustrations. Crown 8vo. 3*s*. 6*d*. cloth extra, gilt edges.

Bird Life of the Bible (from 'Bible Animals'). With 32 Illustrations. Crown 8vo. 3*s*. 6*d*. cloth extra, gilt edges.

Wonderful Nests (from 'Homes without Hands'). With 30 Illustrations. Crown 8vo. 3*s*. 6*d*. cloth extra, gilt edges.

Homes Under the Ground (from 'Homes without Hands'). With 28 Illustrations. Crown 8vo. 3*s*. 6*d*. cloth extra, gilt edges.

CHEMISTRY ENGINEERING, & GENERAL SCIENCE.

Arnott's Elements of Physics or Natural Philosophy. Crown 8vo. 12*s*. 6*d*.

Barrett's English Glees and Part-Songs: their Historical Development. Crown 8vo. 7*s*. 6*d*.

Bourne's Catechism of the Steam Engine. Crown 8vo. 7*s*. 6*d*.
— Handbook of the Steam Engine. Fcp. 8vo. 9*s*.
— Recent Improvements in the Steam Engine. Fcp. 8vo. 6*s*.

Buckton's Our Dwellings, Healthy and Unhealthy. Crown 8vo. 3*s*. 6*d*.

Clerk's The Gas Engine. With Illustrations. Crown 8vo. 7*s*. 6*d*.

Crookes's Select Methods in Chemical Analysis. 8vo. 24*s*.

Culley's Handbook of Practical Telegraphy. 8vo. 16*s*.

Fairbairn's Useful Information for Engineers. 3 vols. crown 8vo. 31*s*. 6*d*.
— Mills and Millwork. 1 vol. 8vo. 25*s*.

Ganot's Elementary Treatise on Physics, by Atkinson. Large crown 8vo. 15*s*.
— Natural Philosophy, by Atkinson. Crown 8vo. 7*s*. 6*d*.

Grove's Correlation of Physical Forces. 8vo. 15*s*.

Haughton's Six Lectures on Physical Geography. 8vo. 15*s*.

Helmholtz on the Sensations of Tone. Royal 8vo. 28*s.*

Helmholtz's Lectures on Scientific Subjects. 2 vols. crown 8vo. 7*s.* 6*d.* each.

Hudson and Gosse's The Rotifera or 'Wheel Animalcules.' With 30 Coloured Plates. 6 parts. 4to. 10*s.* 6*d.* each. Complete, 2 vols. 4to. £3. 10*s.*

Hullah's Lectures on the History of Modern Music. 8vo. 8*s.* 6*d.*

— Transition Period of Musical History. 8vo. 10*s.* 6*d.*

Jackson's Aid to Engineering Solution. Royal 8vo. 21*s.*

Jago's Inorganic Chemistry, Theoretical and Practical. Fcp. 8vo. 2*s.*

Jeans' Railway Problems. 8vo. 12*s.* 6*d.*

Kolbe's Short Text-Book of Inorganic Chemistry. Crown 8vo. 7*s.* 6*d.*

Lloyd's Treatise on Magnetism. 8vo. 10*s.* 6*d.*

Macalister's Zoology and Morphology of Vertebrate Animals. 8vo. 10*s.* 6*d.*

Macfarren's Lectures on Harmony. 8vo. 12*s.*

Miller's Elements of Chemistry, Theoretical and Practical. 3 vols. 8vo. Part I. Chemical Physics, 16*s.* Part II. Inorganic Chemistry, 24*s.* Part III. Organic Chemistry, price 31*s.* 6*d.*

Mitchell's Manual of Practical Assaying. 8vo. 31*s.* 6*d.*

Noble's Hours with a Three-inch Telescope. Crown 8vo. 4*s.* 6*d.*

Northcott's Lathes and Turning. 8vo. 18*s.*

Owen's Comparative Anatomy and Physiology of the Vertebrate Animals. 3 vols. 8vo. 73*s.* 6*d.*

Piesse's Art of Perfumery. Square crown 8vo. 21*s.*

Richardson's The Health of Nations; Works and Life of Edwin Chadwick, C.B. 2 vols. 8vo. 28*s.*

— The Commonhealth; a Series of Essays. Crown 8vo. 6*s.*

Schellen's Spectrum Analysis. 8vo. 31*s.* 6*d.*

Sennett's Treatise on the Marine Steam Engine. 8vo. 21*s.*

Smith's Air and Rain. 8vo. 24*s.*

Stoney's The Theory of the Stresses on Girders, &c. Royal 8vo. 36*s.*

Tilden's Practical Chemistry. Fcp. 8vo. 1*s.* 6*d.*

Tyndall's Faraday as a Discoverer. Crown 8vo. 3*s.* 6*d.*

— Floating Matter of the Air. Crown 8vo. 7*s.* 6*d.*

— Fragments of Science. 2 vols. post 8vo. 16*s.*

— Heat a Mode of Motion. Crown 8vo. 12*s.*

— Lectures on Light delivered in America. Crown 8vo. 5*s.*

— Lessons on Electricity. Crown 8vo. 2*s.* 6*d.*

— Notes on Electrical Phenomena. Crown 8vo. 1*s.* sewed, 1*s.* 6*d.* cloth.

— Notes of Lectures on Light. Crown 8vo. 1*s.* sewed, 1*s.* 6*d.* cloth.

— Sound, with Frontispiece and 208 Woodcuts. Crown 8vo. 10*s.* 6*d.*

Watts's Dictionary of Chemistry. 9 vols. medium 8vo. £15. 2*s.* 6*d.*

Wilson's Manual of Health-Science. Crown 8vo. 2*s.* 6*d.*

THEOLOGICAL AND RELIGIOUS WORKS.

Arnold's (Rev. Dr. Thomas) Sermons. 6 vols. crown 8vo. 5*s.* each.

Boultbee's Commentary on the 39 Articles. Crown 8vo. 6*s.*

Browne's (Bishop) Exposition of the 39 Articles. 8vo. 16*s.*

Bullinger's Critical Lexicon and Concordance to the English and Greek New Testament. Royal 8vo. 15*s.*

Colenso on the Pentateuch and Book of Joshua. Crown 8vo. 6*s.*

Conder's Handbook of the Bible. Post 8vo. 7*s.* 6*d.*

Conybeare & Howson's Life and Letters of St. Paul :—
Library Edition, with Maps, Plates, and Woodcuts. 2 vols. square crown 8vo. 21*s.*
Student's Edition, revised and condensed, with 46 Illustrations and Maps. 1 vol. crown 8vo. 7*s.* 6*d.*

Cox's (Homersham) The First Century of Christianity. 8vo. 12*s.*

Davidson's Introduction to the Study of the New Testament. 2 vols. 8vo. 30*s.*

Edersheim's Life and Times of Jesus the Messiah. 2 vols. 8vo. 24*s.*
— Prophecy and History in relation to the Messiah. 8vo. 12*s.*

Ellicott's (Bishop) Commentary on St. Paul's Epistles. 8vo. Corinthians I. 16*s.* Galatians, 8*s.* 6*d.* Ephesians, 8*s.* 6*d.* Pastoral Epistles, 10*s.* 6*d.* Philippians, Colossians and Philemon, 10*s.* 6*d.* Thessalonians, 7*s.* 6*d.*
— Lectures on the Life of our Lord. 8vo. 12*s.*

Ewald's Antiquities of Israel, translated by Solly. 8vo. 12*s.* 6*d.*
— History of Israel, translated by Carpenter & Smith. 8 vols. 8vo. Vols. 1 & 2, 24*s.* Vols. 3 & 4, 21*s.* Vol. 5, 18*s.* Vol. 6, 16*s.* Vol. 7, 21*s.* Vol. 8, 18*s.*

Hobart's Medical Language of St. Luke. 8vo. 16*s.*

Hopkins's Christ the Consoler. Fcp. 8vo. 2*s.* 6*d.*

Jukes's New Man and the Eternal Life. Crown 8vo. 6*s.*
— Second Death and the Restitution of all Things. Crown 8vo. 3*s.* 6*d.*
— Types of Genesis. Crown 8vo. 7*s.* 6*d.*
— The Mystery of the Kingdom. Crown 8vo. 3*s.* 6*d.*

Lenormant's New Translation of the Book of Genesis. Translated into English. 8vo. 10*s.* 6*d.*

Lyra Germanica : Hymns translated by Miss Winkworth. Fcp. 8vo. 5*s.*

Macdonald's (G.) Unspoken Sermons. Two Series, Crown 8vo. 3*s.* 6*d.* each.
— The Miracles of our Lord. Crown 8vo. 3*s.* 6*d.*

Manning's Temporal Mission of the Holy Ghost. Crown 8vo. 8*s.* 6*d.*

Martineau's Endeavours after the Christian Life. Crown 8vo. 7*s.* 6*d.*
— Hymns of Praise and Prayer. Crown 8vo. 4*s.* 6*d.* 32mo. 1*s.* 6*d.*
— Sermons, Hours of Thought on Sacred Things. 2 vols. 7*s.* 6*d.* each.

Monsell's Spiritual Songs for Sundays and Holidays. Fcp. 8vo. 5*s.* 18mo. 2*s.*

Müller's (Max) Origin and Growth of Religion. Crown 8vo. 7*s.* 6*d.*
— — Science of Religion. Crown 8vo. 7*s.* 6*d.*

Newman's Apologia pro Vitâ Suâ. Crown 8vo. 6*s.*
— The Idea of a University Defined and Illustrated. Crown 8vo. 7*s.*
— Historical Sketches. 3 vols. crown 8vo. 6*s.* each.
— Discussions and Arguments on Various Subjects. Crown 8vo. 6*s.*
— An Essay on the Development of Christian Doctrine. Crown 8vo. 6*s.*
— Certain Difficulties Felt by Anglicans in Catholic Teaching Considered. Vol. 1, crown 8vo. 7*s.* 6*d.* Vol. 2, crown 8vo. 5*s.* 6*d.*
— The Via Media of the Anglican Church, Illustrated in Lectures, &c. 2 vols. crown 8vo. 6*s.* each
— Essays, Critical and Historical. 2 vols. crown 8vo. 12*s.*
— Essays on Biblical and on Ecclesiastical Miracles. Crown 8vo. 6*s.*
— An Essay in Aid of a Grammar of Assent. 7*s.* 6*d.*

Overton's Life in the English Church (1660–1714). 8vo. 14*s.*

Supernatural Religion. Complete Edition. 3 vols. 8vo. 36*s.*

Younghusband's The Story of Our Lord told in Simple Language for Children. Illustrated. Crown 8vo. 2*s.* 6*d.* cloth plain ; 3*s.* 6*d.* cloth extra, gilt edges.

TRAVELS, ADVENTURES, &c.

Baker's Eight Years in Ceylon. Crown 8vo. 5s.
— Rifle and Hound in Ceylon. Crown 8vo. 5s.

Brassey's Sunshine and Storm in the East. Library Edition, 8vo. 21s. Cabinet Edition, crown 8vo. 7s. 6d. Popular Edition, 4to. 6d.
— Voyage in the 'Sunbeam.' Library Edition, 8vo. 21s. Cabinet Edition, crown 8vo. 7s. 6d. School Edition, fcp. 8vo. 2s. Popular Edition, 4to. 6d.
— In the Trades, the Tropics, and the 'Roaring Forties.' Library Edition, 8vo. 21s. Cabinet Edition, crown 8vo. 17s. 6d. Popular Edition, 4to. 6d.

Froude's Oceana; or, England and her Colonies. Crown 8vo. 2s. boards; 2s. 6d. cloth.

Howitt's Visits to Remarkable Places. Crown 8vo. 7s. 6d.

Riley's Athos; or, The Mountain of the Monks. 8vo. 21s.

Three in Norway. By Two of Them. Illustrated. Crown 8vo. 2s. boards; 2s. 6d. cloth.

WORKS OF FICTION.

Beaconsfield's (The Earl of) Novels and Tales. Hughenden Edition, with 2 Portraits on Steel and 11 Vignettes on Wood. 11 vols. crown 8vo. £2. 2s. Cheap Edition, 11 vols. crown 8vo. 1s. each, boards; 1s. 6d. each, cloth.

Lothair.	Contarini Fleming.
Sybil.	Alroy, Ixion, &c.
Coningsby.	The Young Duke, &c.
Tancred.	Vivian Grey.
Venetia.	Endymion.
Henrietta Temple.	

Brabourne's (Lord) Friends and Foes from Fairyland. Crown 8vo. 6s.

Caddy's (Mrs.) Through the Fields with Linnæus: a Chapter in Swedish History. 2 vols. crown 8vo. 16s.

Gilkes' Boys and Masters. Crown 8vo. 3s. 6d.

Haggard's (H. Rider) She: a History of Adventure. Crown 8vo. 6s.
— — Allan Quatermain. Illustrated. Crown 8vo. 6s.

Harte (Bret) On the Frontier. Three Stories. 16mo. 1s.
— — By Shore and Sedge. Three Stories. 16mo. 1s.
— — In the Carquinez Woods. Crown 8vo. 1s. boards; 1s. 6d. cloth.

Lyall's (Edna) The Autobiography of a Slander. Fcp. 1s. sewed.

Melville's (Whyte) Novels. 8 vols. fcp. 8vo. 1s. each, boards; 1s. 6d. each, cloth.

Digby Grand.	Good for Nothing.
General Bounce.	Holmby House.
Kate Coventry.	The Interpreter.
The Gladiators.	The Queen's Maries.

Molesworth's (Mrs.) Marrying and Giving in Marriage. Crown 8vo. 2s. 6d.

Novels by the Author of 'The Atelier du Lys':

The Atelier du Lys; or, An Art Student in the Reign of Terror. Crown 8vo. 2s. 6d.

Mademoiselle Mori: a Tale of Modern Rome. Crown 8vo. 2s. 6d.

In the Olden Time: a Tale of the Peasant War in Germany. Crown 8vo. 2s. 6d.

Hester's Venture. Crown 8vo. 2s. 6d.

Oliphant's (Mrs.) Madam. Crown 8vo. 1s. boards; 1s. 6d. cloth.
— — In Trust: the Story of a Lady and her Lover. Crown 8vo. 1s. boards; 1s. 6d. cloth.

Payn's (James) The Luck of the Darrells. Crown 8vo. 1*s.* boards; 1*s.* 6*d.* cloth.
— — Thicker than Water. Crown 8vo. 1*s.* boards; 1*s.* 6*d.* cloth.

Reader's Fairy Prince Follow-my-Lead. Crown 8vo. 2*s.* 6*d.*
— The Ghost of Brankinshaw; and other Tales. Fcp. 8vo. 2*s.* 6*d.*

Sewell's (Miss) Stories and Tales. Crown 8vo. 1*s.* each, boards; 1*s.* 6*d.* cloth; 2*s.* 6*d.* cloth extra, gilt edges.

Amy Herbert. Cleve Hall.	A Glimpse of the World.
The Earl's Daughter.	Katharine Ashton.
Experience of Life.	Laneton Parsonage.
Gertrude. Ivors.	Margaret Percival. Ursula.

Stevenson's (R. L.) The Dynamiter. Fcp. 8vo. 1*s.* sewed; 1*s.* 6*d.* cloth.
— — Strange Case of Dr. Jekyll and Mr. Hyde. Fcp. 8vo. 1*s.* sewed; 1*s.* 6*d.* cloth.

Sturgis' Thraldom: a Story. Crown 8vo. 6*s.*

Trollope's (Anthony) Novels. Fcp. 8vo. 1*s.* each, boards; 1*s.* 6*d.* cloth.

The Warden	Barchester Towers.

POETRY AND THE DRAMA.

Armstrong's (Ed. J.) Poetical Works. Fcp. 8vo. 5*s.*
— (G. F.) Poetical Works:—

Poems, Lyrical and Dramatic. Fcp. 8vo. 6*s.*	King Saul. Fcp. 8vo. 5*s.*
	King David. Fcp. 8vo. 6*s.*
Ugone: a Tragedy. Fcp. 8vo. 6*s.*	King Solomon. Fcp. 8vo. 6*s.*
A Garland from Greece. Fcp. 8vo. 9*s.*	Stories of Wicklow. Fcp. 8vo. 9*s.*

Bowen's Harrow Songs and other Verses. Fcp. 8vo. 2*s.* 6*d.*; or printed on hand-made paper, 5*s.*

Bowdler's Family Shakespeare. Medium 8vo. 14*s.* 6 vols. fcp. 8vo. 21*s.*

Dante's Divine Comedy, translated by James Innes Minchin. Crown 8vo. 15*s.*

Goethe's Faust, translated by Birds. Large crown 8vo. 12*s.* 6*d.*
— — translated by Webb. 8vo. 12*s.* 6*d.*
— — edited by Selss. Crown 8vo. 5*s.*

Ingelow's Poems. Vols. 1 and 2, fcp. 8vo. 12*s.*
— Lyrical and other Poems. Fcp. 8vo. 2*s.* 6*d.* cloth, plain; 3*s.* cloth, gilt edges.

Macaulay's Lays of Ancient Rome, with Ivry and the Armada. Illustrated by Weguelin. Crown 8vo. 3*s.* 6*d.* gilt edges.

The same, Popular Edition. Illustrated by Scharf. Fcp. 4to. 6*d.* swd., 1*s.* cloth.

Nesbit's Lays and Legends. Crown 8vo. 5*s.*

Reader's Voices from Flowerland, a Birthday Book, 2*s.* 6*d.* cloth, 3*s.* 6*d.* roan.

Southey's Poetical Works. Medium 8vo. 14*s.*

Stevenson's A Child's Garden of Verses. Fcp. 8vo. 5*s.*

Virgil's Æneid, translated by Conington. Crown 8vo. 9*s.*
— Poems, translated into English Prose. Crown 8vo. 9*s.*

AGRICULTURE, HORSES, DOGS AND CATTLE.

Fitzwygram's Horses and Stables. 8vo. 5*s.*

Lloyd's The Science of Agriculture. 8vo. 12*s.*

Loudon's Encyclopædia of Agriculture. 21*s.*

Steel's Diseases of the Ox, a Manual of Bovine Pathology. 8vo. 15*s.*

Stonehenge's Dog in Health and Disease. Square crown 8vo. 7*s.* 6*d.*
— Greyhound. Square crown 8vo. 15*s.*
Taylor's Agricultural Note Book. Fcp. 8vo. 2*s.* 6*d.*
Ville on Artificial Manures, by Crookes. 8vo. 21*s.*
Youatt's Work on the Dog. 8vo. 6*s.*
— — — — Horse. 8vo. 7*s.* 6*d.*

SPORTS AND PASTIMES.

The Badminton Library of Sports and Pastimes. Edited by the Duke of Beaufort and A. E. T. Watson. With numerous Illustrations. Cr. 8vo. 10*s.* 6*d.* each.
Hunting, by the Duke of Beaufort, &c.
Fishing, by H. Cholmondeley-Pennell, &c. 2 vols.
Racing, by the Earl of Suffolk, &c.
Shooting, by Lord Walsingham, &c. 2 vols.
Cycling. By Viscount Bury.
*** *Other Volumes in preparation.*

Campbell-Walker's Correct Card, or How to Play at Whist. Fcp. 8vo. 2*s.* 6*d.*
Ford's Theory and Practice of Archery, revised by W. Butt. 8vo. 14*s.*
Francis's Treatise on Fishing in all its Branches. Post 8vo. 15*s.*
Longman's Chess Openings. Fcp. 8vo. 2*s.* 6*d.*
Pease's The Cleveland Hounds as a Trencher-Fed Pack. Royal 8vo. 18*s.*
Pole's Theory of the Modern Scientific Game of Whist. Fcp. 8vo. 2*s.* 6*d.*
Proctor's How to Play Whist. Crown 8vo. 5*s.*
Ronalds's Fly-Fisher's Entomology. 8vo. 14*s.*
Verney's Chess Eccentricities. Crown 8vo. 10*s.* 6*d.*
Wilcocks's Sea-Fisherman. Post 8vo. 6*s.*

ENCYCLOPÆDIAS, DICTIONARIES, AND BOOKS OF REFERENCE.

Acton's Modern Cookery for Private Families. Fcp. 8vo. 4*s.* 6*d.*
Ayre's Treasury of Bible Knowledge. Fcp. 8vo. 6*s.*
Brande's Dictionary of Science, Literature, and Art. 3 vols. medium 8vo. 63*s.*
Cabinet Lawyer (The), a Popular Digest of the Laws of England. Fcp. 8vo. 9*s.*
Cates's Dictionary of General Biography. Medium 8vo. 28*s.*
Gwilt's Encyclopædia of Architecture. 8vo. 52*s.* 6*d.*
Keith Johnston's Dictionary of Geography, or General Gazetteer. 8vo. 42*s.*
M'Culloch's Dictionary of Commerce and Commercial Navigation. 8vo. 63*s.*
Maunder's Biographical Treasury. Fcp. 8vo. 6*s.*
— Historical Treasury. Fcp. 8vo. 6*s.*
— Scientific and Literary Treasury. Fcp. 8vo. 6*s.*
— Treasury of Bible Knowledge, edited by Ayre. Fcp. 8vo. 6*s.*
— Treasury of Botany, edited by Lindley & Moore. Two Parts, 12*s.*
— Treasury of Geography. Fcp. 8vo. 6*s.*
— Treasury of Knowledge and Library of Reference. Fcp. 8vo. 6*s.*
— Treasury of Natural History. Fcp. 8vo. 6*s.*
Quain's Dictionary of Medicine. Medium 8vo. 31*s.* 6*d.*, or in 2 vols. 34*s.*
Reeve's Cookery and Housekeeping. Crown 8vo. 7*s.* 6*d.*
Rich's Dictionary of Roman and Greek Antiquities. Crown 8vo. 7*s.* 6*d.*
Roget's Thesaurus of English Words and Phrases. Crown 8vo. 10*s.* 6*d.*
Willich's Popular Tables, by Marriott. Crown 8vo. 10*s.* 6*d.*